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North Saskatchewan River
Characterization of Water Quality in the Vicinity of Edmonton (1982-83)
Part I

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Water Quality Control Branch

NORTH SASKATCHEWAN RIVER:
CHARACTERIZATION OF WATER QUALITY
IN THE VICINITY OF EDMONTON (1982-1983)

PART I

INTRODUCTION, WATER CHEMISTRY, CHLOROPHYLL, BACTERIOLOGY

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EXECUTIVE SUMMARY

Beginning in the spring of 1982, a two-year study of the section of the North Saskatchewan River impacted by the greater Edmonton urban area was undertaken by the Water Quality Control Branch, Pollution Control Division, Alberta Environment. The principal purposes of the study were to characterize this section of the river chemically and biologically, to compare water quality in this section with the Alberta Surface Water Quality Objectives, and to assess major impacts of the greater Edmonton area on the river biota and water quality. Study locations were spaced strategically throughout the study section from a relatively unimpacted upstream location at Devon to a relatively well mixed location at Pakan, 160 km downstream. Left-bank, right-bank, and centre-channel sites were sampled at most locations.

Sampling included most standard chemical variables, metals, organics, pesticides, and one sediment sampling event. Complementary biological sampling (zoobenthos, algal chlorophyll-a, bacteria) was also done, because the biota tend to act as impact integrators over time and thereby reflect synergistic effects. This summary refers to both Part One and Part Two of the report.

Characterization

The total annual discharge of the North Saskatchewan River in 1982 was considerably above normal, although most of the additional volume was attributable to unusually high flows during late June and early July. Total annual discharge in 1983, on the other hand, was below normal, due mainly to very low flows in June and July.

Some variables tended to increase in a downstream direction due to natural causes, some were very much influenced by flow regime (i.e. dilution, seasonal, and flow-regulation effects), and others were affected by the mixing regime of the river. Several variables were influenced by inputs from the greater Edmonton urban area.

The chemical and physical variables affected by urban area inputs included temperature, dissolved oxygen, biochemical and chemical oxygen demand, non-filterable residues, specific conductance, total dissolved solids, the dissolved fraction of total organic carbon, total nitrogen, ammonia nitrogen, nitrate-plus-nitrite nitrogen, total phosphorus, sodium, potassium, chloride, sulfate, nickel, manganese, lead, and zinc. Loading estimates indicated that the main sources of increase for most of these variables in the Edmonton urban area were municipal wastewater treatment plants. For many organic substances, increases in values measured downstream of Edmonton were usually very low and no statistically significant pattern could be determined.

Some chemical variables were present either at levels below analytical detection limits or were affected very little by urban inputs. These variables included alkalinity, bicarbonate, fluoride, particulate phosphorus, and many metals (magnesium, calcium, mercury, cadmium, molybdenum, beryllium, copper, chromium, vanadium, arsenic, iron, aluminum).

Chlorophyll-a showed a marked summer increase in downstream direction for both planktonic and epilithic algae. Planktonic forms flow with the river, whereas epilithic forms are attached to rocks and remain until scoured away the following spring. All bacterial forms (total coliforms, fecal coliforms, fecal streptococci, and heterotrophic bacteria) increased greatly in number immediately below the Gold Bar Wastewater Treatment Plant and remained at high levels in the downstream part of the study section.

Due to inputs of organic matter and nutrients, sedimentation, and plant growth on the river bed substrates in and downstream of Edmonton, the zoobenthos changed from an assembly of clean-water taxa (dominated by certain species of stoneflies, mayflies, and caddisflies) at Devon to a less diverse and more abundant fauna characterized by pollution tolerant taxa (such as oligochaetes and chironomids) below Gold Bar. However, there was evidence of recovery in the zoobenthos further downstream. Zoobenthic data were useful in the interpretation of certain chemical data. The zoobenthic study also showed that temporal and spatial changes in the composition and numerical density of the zoobenthic community could be of great value in the scheduling of sampling and the selection of sites for future detailed water quality investigations.

Alberta Surface Water Quality Objectives

No objectives have been formulated for many of the variables assessed in this study, such as major ions, many specific trace organic compounds, total organic carbon, dissolved inorganic carbon, chemical oxygen demand, chlorophyll-a, and zoobenthos. The chemical variables in the preceding group are considered harmless at the concentrations measured in this study.

Many variables, namely temperature, dissolved oxygen, biochemical oxygen demand, most metals and certain organic compounds, complied with the Objectives or were below the analytical detection limits.

Some variables, namely total phenolic compounds, scattered or isolated occurrences of a few other organic compounds, ammonia -nitrogen, lead, and zinc, occasionally exceeded the Objectives. Natural levels of zinc at Devon frequently approached the Objective level for zinc.

A few variables frequently or regularly exceeded the Objectives: natural levels of iron and manganese exceeded the Objectives; 85% to 95% of samples for total phosphorus and 30% of samples for total nitrogen exceeded the Objectives at Pakan; 21% to 35% of all bacterial samples exceeded the Objectives at Pakan. Exceedence percentages for nutrients and bacteria were usually higher in close proximity to wastewater treatment plant outfalls.

Impacts

The greatest actual and potential impacts from the greater Edmonton urban area were associated with high nutrient loads, particularly phosphorus and nitrogen; direct effects were evident in increased plant growth (measured as chlorophyll-a), whereas secondary and synergistic effects contributed to some decrease in dissolved oxygen levels, some increase in biochemical oxygen demand values, and cyclic and compositional changes in the zoobenthic community. Smaller impacts were associated with particulate organic matter and total organic carbon loads; direct effects were linked to the abundance of zoobenthos and heterotrophic bacteria, whereas synergistic effects impacted dissolved oxygen, chemical and biochemical oxygen demand.

Another important impact was associated with high bacterial numbers, which affect some potential uses for the river water.

This study did not address the short-lived taste and odor problems that usually occur at the time of spring runoff. However, the concentrations of the substances suspected of causing these organoleptic problems were usually very low.

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LIST OF ABBREVIATIONS

AEC	Alberta Environmental Centre, Vegreville, Alberta
ASWQO	Alberta Surface Water Quality Objectives
BOD	biochemical oxygen demand
COD	chemical oxygen demand
chl-a	chlorophyll-a
C.L.I.	Canada Land Inventory
$cm \cdot y^{-1}$	centimetres per year
km	kilometre
$km \cdot h^{-1}$	kilometres per hour
$kg \cdot d^{-1}$	kilograms per day
L	litre
$L \cdot s^{-1}$	litres per second
m	metre
mL	millilitre
$mg \cdot L^{-1}$	milligrams per litre
µm	micrometre (= mm X 10^{-3})
$\mu g \cdot L^{-1}$	micrograms per litre
$\mu S \cdot cm^{-1}$	micro-Siemens per centimetre (a measure of conductance)
mm	millimetre
$m^3 \cdot s^{-1}$	cubic metres per second
nm	nanometre (= 10^{-9} metre); 1 nm = 10 Angstrom units

TOC	total organic carbon
DOC	dissolved organic carbon
DIC	dissolved inorganic carbon
TPC	total particulate carbon
TC	total coliform bacteria
FC	fecal coliform bacteria
FS	fecal streptococci
MF	membrane filtration technique
MPN	most probable number
EPA	Environmental Protection Agency (United States)
GBWTP	Gold Bar Wastewater Treatment Plant (City of Edmonton)
NSR	North Saskatchewan River
OECD	Organization for Economic Co-operation and Development
n	number (no. of cases used in calculating probability)
P	probability (statistical)
ND	not detectable
NFR	non-filterable residue
TN	total nitrogen
TKN	total Kjeldahl nitrogen
NH_3-N	ammonia nitrogen
NO_2-N	nitrite nitrogen
NO_2+NO_3-N	nitrite plus nitrate nitrogen
PCBs	polychlorinated biphenyls
TDS	total dissolved solids
TP	total phosphorus

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Chemical analyses were conducted at the Alberta Environmental Centre (Vegreville), the Gold Bar Wastewater Laboratory and the Rossdale Water Treatment Laboratory of the Water and Sanitation Department, City of Edmonton, the Environmental Protection Service microbiology laboratory of Environment Canada, Western and Northern Region (Edmonton), and the National Water Research Institute (Burlington).

1.0 INTRODUCTION

The North Saskatchewan River (NSR) is a major tributary of the Saskatchewan-Nelson river system, which drains a large part of three Canadian provinces (Alberta, Saskatchewan, and Manitoba), as well as the State of North Dakota. From its source, the Saskatchewan Glacier on the Alberta-British Columbia border, the NSR flows eastward across central Alberta and into Saskatchewan where it joins the South Saskatchewan River east of Prince Albert to form the Saskatchewan River. The Saskatchewan River flows into Cedar Lake and then Lake Winnipeg in Manitoba, eventually draining into the Hudson Bay through the Nelson River (Fig. 1.1).

Historically, the NSR was an important transportation and communication route, and several early settlements were established along its banks. Many of these settlements have grown into regional population centres (among which Edmonton is the largest) which are dependent on the river, both as a source of water for domestic, agricultural, and industrial purposes, and as a receiving water for various domestic and industrial waste-water effluents. During the past half century, there have been large increases in human population and in agricultural and industrial activities in the NSR drainage basin. With the growth in population, the river and its valley have also become the focus of many recreational activities and aesthetic interests. More recently, dams and diversions have resulted in alterations in river flow.

The cultural activities of a growing human population, unnatural changes in flow regimes, and variations in climatic conditions have combined to produce fluctuations in both the quantity and quality of water in the NSR. Changes in economic and social conditions have contributed to conflicts of interest concerning river use and differences in the conception of water quality in the river.

In 1981, a contemporary study of the NSR was planned by the Water Quality Control Branch of Alberta Environment. This was done because of an apparent public conception that the NSR water quality was bad and getting worse, and because of a Departmental need for updated and upgraded water quality data and the re-evaluation of impacts due to the concentration of population and industry in and near the City of Edmonton. No one year is likely to be typical, so the plan was for at least a two-year study. Because the region including Edmonton City and immediate vicinity is the main user and impacter of the NSR, the study focussed on a section of the river extending from an essentially unimpacted site upstream of Edmonton to a site well inside an hypothesized recovery zone, where mixing was believed to be complete. Sampling was carried out during the ice-free periods of 1982 and 1983, and on two winter dates in 1984.

The principal objectives of this study were:

1. to provide a spatial and temporal characterization of the NSR water quality in the vicinity of Edmonton by assessing bank-to-bank, upstream-downstream, and seasonal differences.
2. to compare present NSR water quality to the Alberta Surface Water Quality Objectives (ASWQO, Alberta Environment 1977) or to other

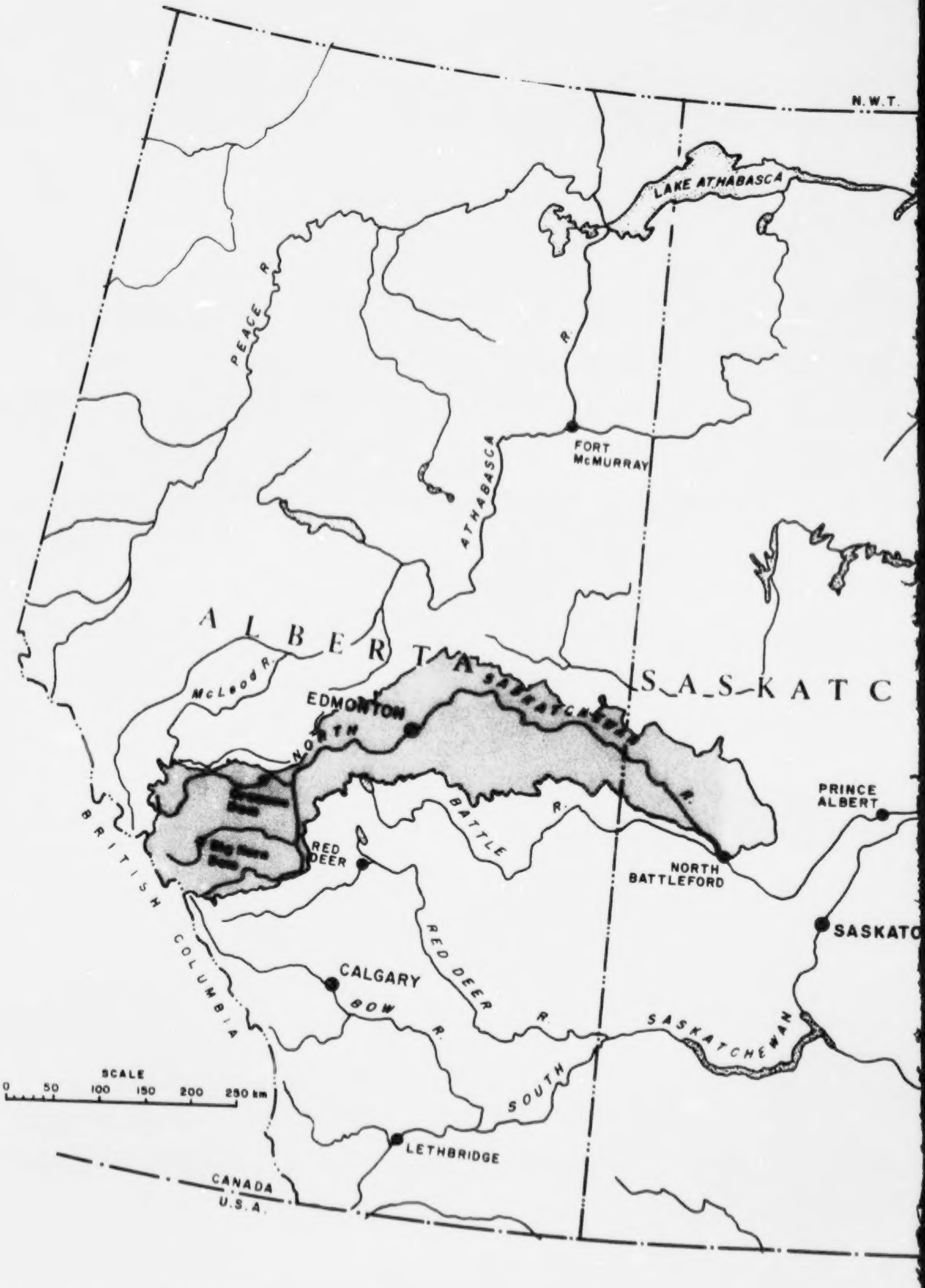
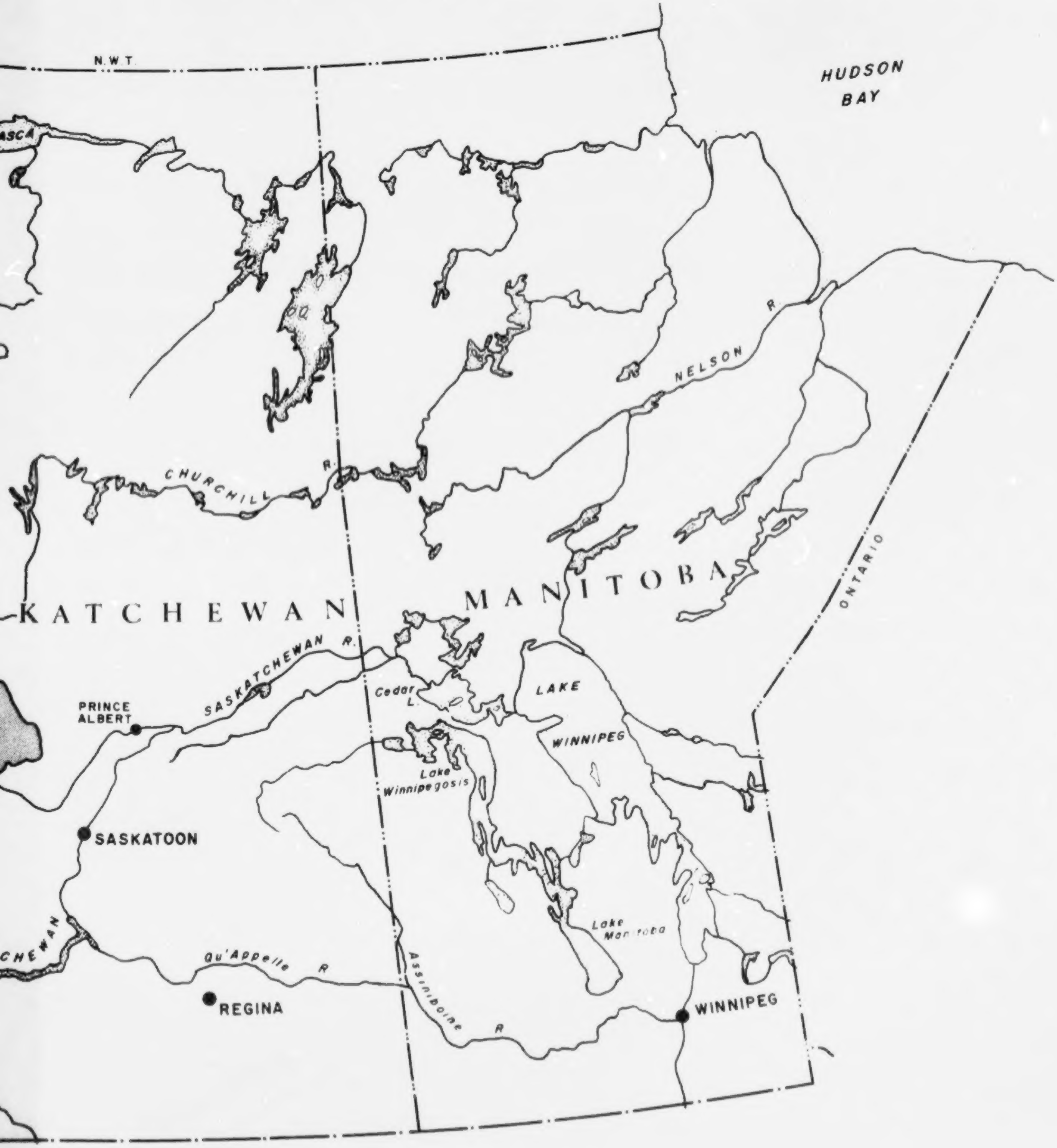

N.W.T.
LAKE ATHABASCA
PEACE R.
ATHABASCA R.
FORT McMURRAY
ALBERTA
SASKATC
McLeod R.
EDMONTON
NORTH SASKATCHEWAN R.
PRINCE ALBERT
BATTLE R.
RED DEER
NORTH BATTLEFORD
SASKATO
BRITISH COLUMBIA
CALGARY
BOW R.
RED DEER R.
SOUTH SASKATCHEWAN
SCALE
0 50 100 150 200 250 km
LETHBRIDGE
CANADA
U.S.A.

Fig. 1.1 SASKATCHEWAN - NELSON BASIN
SHOWING THE NORTH SASKATCHEWAN RIVER


N.W.T.
HUDSON BAY
ASCA
CHURCHILL R.
NELSON R.
KATCHEWAN
MANITOBA
ONTARIO
SASKATCHEWAN R.
PRINCE ALBERT
Cedar L.
LAKE WINNIPEG
Lake Winnipegosis
SASKATOON
CHEWAN
Qu'Appelle R
Assiniboine R
Lake Manitoba
REGINA
WINNIPEG

RIVER

criteria, if no specific Alberta objectives had been formulated.

3. to assess impacts of major developments in the Edmonton region on the NSR, and to provide a general evaluation of point sources which affect the general water quality or "well being" of the river.

Some comments and explanations concerning these three objectives follow.

Characterization: The first objective of this study was to relate river basin and flow characteristics, developments, and related aspects to general water quality. The results were expected to reflect the fact that growth and development have occurred, producing changes in water quality, and that growth and resultant changes to water quality will continue to occur. In a continuously changing environment, there is an ongoing need for new baseline data and for updating or upgrading the existing data base. Additions or changes in emphasis were made during the course of this study to fill data gaps, to assess newly perceived or suspected point-source inputs, to aid in comparisons with previous studies, and to reflect planning requirements. It was not the purpose of this study to provide day-to-day monitoring of selected variables which are suspected of exceeding limits or guidelines for a few hours or a few days under extreme conditions, such as those which occur during spring run-off or storm events. Findings are presented in "Results and Discussion" subsections of each major section dealing with a particular variable or group of variables.

Surface Water Quality Objectives: In 1977, provincial water quality guidelines and objectives were published for Alberta (ASWQO, Alberta Environment 1977) to provide protection for the most sensitive uses for which the resource is required (propagation of aquatic life, public water supply, and direct contact recreation). The numerical values established for the water quality variables represent goals which should be achieved or surpassed. It should be noted that the ASWQO were not designed for particular watersheds, but were intended to apply throughout the province. Consequently, they cannot account for the extremes in natural concentrations which can be expected to occur over such a large geographical area. Therefore, natural concentrations of certain substances may exceed the objectives in some watersheds (pristine or developed), depending on their unique geochemical characteristics.

Certain variables have not yet been included in the ASWQO or, for that matter, in any available set of objectives. In these cases, available objectives or appropriate published guidelines or criteria have been consulted in assessing the importance of the concentrations or values encountered.

Impacts: When certain variables approached or exceeded the ASWQO, their actual or potential impacts were considered from an appropriate point of view, such as the impairment of water quality, the impediment to legitimate use of the river, the effect on other variables under assessment, or the effect on the biotic community.

For purposes of organizing schedules and sampling, the river was considered to have three components: the flowing water and its non-living dissolved and suspended load; the stationary sedimentary material comprising the river bed; the biota or biological life in the water and within or upon the underlying sediments. To the majority of people, the most obvious aspect of a large river such as the NSR is the flowing water, especially its appearance, its taste, or odor, and the "invisible" dissolved substances which it carries. Consequently, the physical and chemical variables of the water component were monitored most frequently and intensively. Calculations of the loading contributions from major tributaries and effluents were done to aid in identifying point-source impacts. Two biological variables, the bacteria and the river- (or potamo-) phytoplankton, were usually sampled on the same schedule as the water component. Because of the water's short residence time within the study section of the NSR, it was believed that cumulative effects might be reflected better by non-flowing components. Therefore, the study included a fairly intensive survey of the invertebrate animals on and in the bottom sediments and a preliminary examination of the epilithic algae (i.e. the algae attached to the surface of rocks). A macrophyte survey was not included in the present study; had macrophyte development been widespread or consistent in the NSR prior to the conception of this study, a survey of distribution and abundance would have been included for the same reasons that surveys of zoobenthos and epilithic algae were included. The fish community in the river was not included in this study. Because of the absence of data on the chemistry of the riverbed sediments, a preliminary survey was undertaken in the hope that it would aid in interpretation and that it would clarify the need for a more detailed investigation.

In overview, this report consists of three parts. Part One begins with a summary of river basin characteristics and a review of existing information on NSR mixing properties. This is followed by a summary of sampling dates and locations, measured variables, field methods, and laboratory methods. The results sections of Part One include temperature, dissolved oxygen, results of analyses for major ions, metals, organic compounds, macronutrients, chlorophyll-a surveys, carbon, bacteria, and BOD/COD. Results from sediment analyses are included in the metals and organic compounds sections.

Part Two of this report is an analysis of the zoobenthos (i.e. those insect larvae, worms, and other invertebrates inhabiting the bottom sediments under the flowing water) and an interpretation of its value as an integrator in determining year-round water quality fluctuations.

Part Three is a compendium of analytical data from Part One and Part Two of this study. Because all graphs, tables, and discussion in Part One have been drawn from or based on this data base and because no additional data are included in Part Three, it is not intended for general distribution, but will be available upon special request.

2.0 RIVER BASIN CHARACTERISTICS

2.1 Location

The North Saskatchewan River (NSR) originates in the Rocky Mountains and flows eastward through Alberta to be joined by the South Saskatchewan River in Saskatchewan. The City of Edmonton is located along the river midway between its origin in the mountains and its points of crossing the Alberta-Saskatchewan border. The study section of the river extended from Devon (113° 45'W, 53° 22'N) to Pakan (112° 29'W, 53° 59'N), or approximately 40 km upstream and 123 km downstream of Edmonton City centre, respectively. General location and NSR drainage basin details are shown in Figure 2.1.

2.2 Climate

The climate of the region is continental, producing warm summers and cold winters. The monthly mean temperature ranges from -17°C in January to +17.2°C in July. The winter season (mean daily temperature 0°C or less) usually begins the first week in November and ends in early April. Winter temperatures have a greater range than summer temperatures, with January usually being the coldest month. Frost-free days average 100; summer temperatures seldom exceed 32°C and have never exceeded 38° C. The mean annual temperature in Edmonton for the period 1931-1971 was 2.7°C.

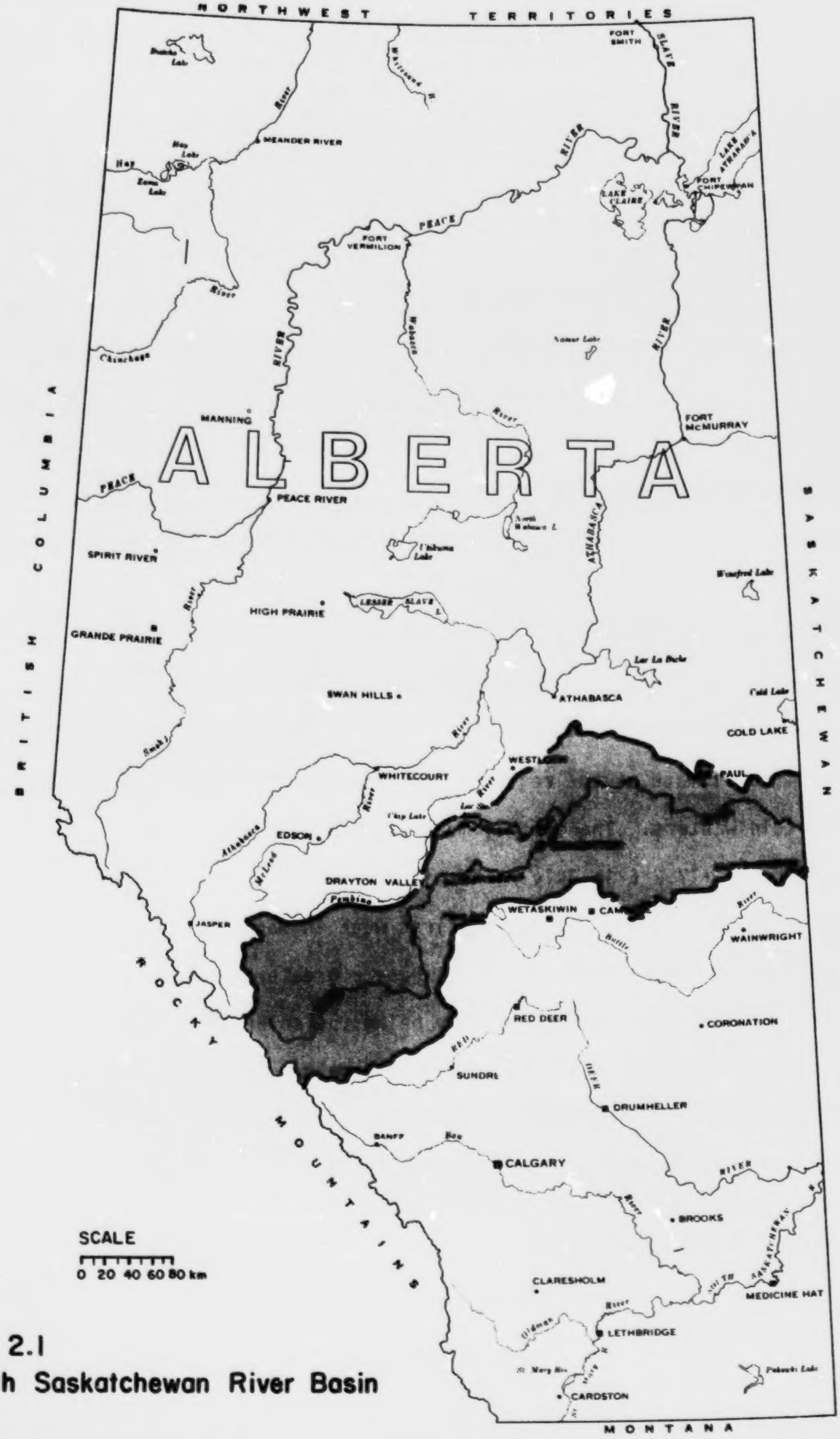

NORTHWEST TERRITORIES
FORT SMITH
SLAVE RIVER
MEANDER RIVER
Hay Lake
Zama Lake
Hay
LAKE ATHABASCA
FORT CHIPEWYAN
LAKE CLAIRE
PEACE RIVER
FORT VERMILION
Chinchaga
Wabasca River
RIVER
Namur Lake
FORT McMURRAY
MANNING
ALBERTA
PEACE
PEACE RIVER
North Wabasca L.
Utikuma Lake
ATHABASCA
SPIRIT RIVER
Winefred Lake
HIGH PRAIRIE
LESSER SLAVE L.
GRANDE PRAIRIE
Lac La Biche
SWAN HILLS
ATHABASCA
Cold Lake
COLD LAKE
Smoky
River
WESTLOCK
WHITECOURT
PAUL
Chip Lake
Lac Ste. Anne
EDSON
Athabasca
McLeod
DRAYTON VALLEY
Pembina
JASPER
WETASKIWIN
CAMROSE
Battle
WAINWRIGHT
RED DEER
CORONATION
SUNDRE
RED DEER
DRUMHELLER
BANFF
Bow
CALGARY
RIVER
BROOKS
SOUTH SASKATCHEWAN
CLARESHOLM
MEDICINE HAT
Oldman
River
LETHBRIDGE
St. Mary Res.
Pakowki Lake
CARDSTON
MONTANA
BRITISH COLUMBIA
SASKATCHEWAN
ROCKY MOUNTAINS
SCALE
0 20 40 60 80 km

Fig. 2.1
North Saskatchewan River Basin

The Edmonton area has the lowest average wind speed (15 $km \cdot h^{-1}$) of cities on the Canadian Prairie. The wind blows most frequently from the Northwest (NW quadrant) and South (SE to SW). Highest mean wind speeds are from the Northwest (NW quadrant) and Southeast (SE quadrant) (Environment Canada 1982).

Precipitation ranges between 30 and 64 cm, averaging 47 $cm \cdot y^{-1}$ (Kathol and McPherson 1975).

2.3 Geology, Geological History

The bedrock directly underlying the North Saskatchewan River within the study area is of late Cretaceous age. It dips westward so that successively younger strata outcrop in a southwesterly direction up to the base of the Rocky Mountains. The Wapiti formation, which lies north of the river throughout the study area, is a combination of the Horseshoe Canyon formation and Belly River formation. To the south of the river, these latter formations are more clearly defined because the marine Bearspaw formation is often present between them. The river has been arbitrarily designated the boundary between the Wapiti formation and the Horseshoe Canyon and Belly River formations (Ceroici 1979).

The Horseshoe Canyon formation consists of fine-grained bentonitic sandstones, silty shales, lenticular coal lenses and beds of bentonite (Ceroici 1979). The Belly River formation is similar, consisting of grey to greenish grey, thick-bedded feldspathic sandstone, grey clayey siltstone, grey and green mudstone, and ironstone concretions (Stein 1976).

Bedrock is exposed along the length of the river, especially upstream of Clover Bar in the City of Edmonton. There has been less erosion downstream of Clover Bar because the river follows the pre-glacial Beverly Channel. Bedrock erosion is also visible along the major tributary creeks (Kathol and McPherson 1975). Saskatchewan sands and gravels deposited as channel-fill in pre-glacial valleys also outcrop along the river (Bayrock and Hughes 1962).

As the Keewatin Glacier retreated about 10,000 years ago, proglacial Lake Edmonton formed against the dam of the retreating glacier. The lake covered the area now occupied by the City of Edmonton, extended beyond Devon to the west, and drained to the south via what is now termed Blackmud Creek, through Saunders and Coal lake channels to the Battle River.

After Lake Edmonton drained, the North Saskatchewan River was formed as one channel of a braided stream flowing over the lake bed. Remnants of the braided area can be seen on present day air photos between Spruce Grove and Devon; downstream of the Edmonton city, the river consisted of a single channel (Bayrock and Hughes 1962).

Most of the area between Devon and Pakan is overlain by glacial till. The till is a poorly sorted mixture of clay, silt, sand and gravel consisting of 80% local bedrock and 20% Canadian Shield igneous and metamorphic rocks. Montmorillonite is the dominant clay mineral.

The railway bridge west of Clover Bar and within Edmonton City marks the boundary of two river reaches. Upstream of this point, the valley is 1 km wide or less, bordered by 60 m cliffs. Downstream of

Clover Bar, the river follows the pre-glacial Beverly channel; the present valley is 2 km wide or wider, bordered by cliffs of less than 40 m (Bayrock and Hughes 1962, Nwachukwu and Neill 1972). Glacial till averages 15 m thick in the Beverly Valley.

2.4 Hydrology

The watershed of the North Saskatchewan River at Edmonton comprises 27,195 km². The Edmonton gauge station at the Low Level Bridge (Water Survey of Canada 05DF001) has a zero elevation of 609.7 m (Kellerhals et al. 1972).

Flow on the North Saskatchewan is regulated by two hydroelectric power dams. The Brazeau Dam, on the main tributary to the North Saskatchewan, began power generation in 1965; the Bighorn Dam on the mainstem was completed in 1972 (Fig. 1.1). These dams lower the flood peaks, shorten the duration of flushing flows by one-half, and augment winter flows (Crosby 1982). The percentage of peak flow reduction decreases downstream as the amount of unregulated watershed increases. Winter flow augmentation also decreases in a downstream direction, although winter flows are two to three times greater at Edmonton than the pre-regulation flows would have been (Doyle and Thompson 1979).

The average annual discharge of the North Saskatchewan River at Edmonton since 1973 is 196 $m^3 \cdot s^{-1}$. The highest mean monthly flow is in June (351 $m^3 \cdot s^{-1}$) and the lowest mean monthly flow is in December (111 $m^3 \cdot s^{-1}$). Mean monthly flows for 1982-1983 are presented in Table 2.1.

TABLE 2.1 Mean monthly discharges ($m^3 \cdot s^{-1}$)* for 1982 and 1983 and historical mean monthly discharges (1973-1983) for the North Saskatchewan River at Edmonton

	1982	1983	Historical
January	103	141	114
February	128	115	119
March	128	126	125
April	240	280	227
May	216	259	280
June	282	240	351
July	742	299	348
August	169	143	212
September	177	119	186
October	182	118	151
November	104	130	125
December	129	107	111
mean	218	173	196

* Water Survey of Canada data (Environment Canada 1983, 1984a, 1985).

The total discharge during 1982 was much greater than the historical mean, but most of this was due to flows greater than twice the long-term mean in July as a result of unusually heavy rainfall throughout the area. Flows during the other months of 1982 were near or sometimes below the mean. Total discharge during 1983 was slightly below the historical mean. Flows in 1983 were below average for all months from May to October, inclusive, and especially low for June and July.

The two reservoirs provide flood protection in the spring-early summer period, but downstream areas could flood during late summer storms. Doyle and Thompson (1979) estimate that the volume of the once in 100-year flood at Edmonton would be smaller by 10% as a result of the dams.

2.5 Groundwater

Southwest of the city the Horseshoe Canyon formation produces poor groundwater yields (0.1 - 0.46 $L{\cdot}s^{-1}$) except in the Millet area. The major pre-glacial tributary of the Beverly Channel, the Stony Valley, contains Saskatchewan sands and gravels which have a high groundwater yield rate (2 - 7.6 $L{\cdot}s^{-1}$). The pre-glacial sands are recharged where the valley is crossed by the North Saskatchewan River on the southwestern edge of the City of Edmonton. The direction of groundwater flow in this area is toward the Stony Valley and the North Saskatchewan River, and then toward the northeast. The river is a major groundwater discharge area; most of the springs along the river bank arise at the drift-bedrock contact (Ceroici 1979).

Calcium-magnesium bicarbonate water predominates in the surficial deposits, whereas bedrock aquifers tend to yield sodium-bicarbonate water. Upstream of the city, bedrock aquifers may yield considerably greater quantities of groundwater than surficial deposits. Chloride concentrations are generally less than 50 $mg \cdot L^{-1}$ in surficial deposits and bedrock. Sulfate concentrations in bedrock groundwater average 100 $mg \cdot L^{-1}$, but are more variable in drift groundwater. Iron is low in bedrock waters, but surficial deposit waters may contain concentrations of over 5 $mg \cdot L^{-1}$. The highest iron concentrations are in water from dune fields and Saskatchewan sands and gravels. In general, total dissolved solids concentrations are usually less than 2500 $mg \cdot L^{-1}$ (Ceroici 1979).

Downstream of Edmonton the river flows through the Beverly Channel. Total dissolved solids in water from the Beverly Channel sands and gravels is less than 500 $mg \cdot L^{-1}$. The dominant cations in this water are calcium and magnesium, and iron concentrations are high. Bedrock water in the area is similar to that upstream of Edmonton. This is of a sodium bicarbonate type, with TDS usually ranging between 1000-2000 $mg \cdot L^{-1}$. Yields of water from the Beverly channel are high, ranging up to 7.6 $L \cdot s^{-1}$ (Stein 1976).

Within the Belly River Formation, groundwater yields vary greatly, but are generally in the low to moderate range. In contrast to yields upstream of Edmonton, the Horseshoe Canyon formation downstream of the city produces good yields from the highly fractured coal seams (Stein 1976).

2.6 Geomorphology, Channel Characteristics

Downstream of the Genesee Bridge, the river takes the form of a single channel, with few mid-channel gravel bars. The valley is narrow through this stretch. Between Devon and Edmonton, the channel wanders irregularly, and several bends are cut into high cliffs of weathered sandstone. Scour holes 2 to 3 m deep have formed on the outside of bends near Devon, and some bank slumping has resulted (Doyle and Thompson 1979).

Bed materials in the NSR are primarily gravel; particle sizes tend to decrease in the downstream direction, although bed materials at Devon and Edmonton are similar (Doyle and Thompson 1979). Between Edmonton and the Saskatchewan border, the bed material is also gravel, primarily quartzite. The median size of the gravel ranges from 0.25 mm to 23 mm with a modal size of 16 mm diminishing in downstream direction (Table 2.2). Below the gravel bed, from Edmonton to the border, the substrate consists of a 4 to 5 m thick gravel layer in the upper reaches, and layers of silty-clay and sandy silt in the lower reaches (Nwachukwu and Neill 1972).

There has been little alteration in the bed profile downstream of Edmonton. A comparison of surveys done in 1912 and again in the early 50's shows little change, and there appears to have been no further change due to recent major flood events.

TABLE 2.2 Summary* of bed material size near water's edge at various locations from the Saskatchewan border to Lodgepole, North Saskatchewan River.

River km	Location	Size (mm)** D_{50}	D_{85}	D_{90}	Largest
550	Lodgepole, right side	74	193		350
484	Berrymoor Ferry, right	38	89		140
484	Berrymoor Ferry, left	41	70		150
443	Genesee Ferry, left	32	54		120
381	Devon Bridge, right	16	42		70
339	High Level Bridge, left	23		95	128
291	Ft. Saskatchewan, left	16		64	128
224	Warspite, left	16		61	128
80	Elk Point Bridge, left	12		64	128
8	N. Sask. border, right	0.25		0.40	16

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* Adapted from Doyle and Thompson (1979) and Nwachukwu and Neill (1972)

** D_{50} = median size by weight

2.7 Soils

From the mountains to a point near Drayton Valley, the North Saskatchewan River flows through an area of grey wooded soils. These soils developed under forest. They are low in nutrients and organic matter and, consequently, are considered poor for agriculture (C.L.I. class 4 or lower). Additionally, this area (agroclimatic zone 5H) has a very short growing season, the average frost-free period being less than 60 days (Brocke 1977).

Further east in the NSR drainage basin, soil productivity potential and growing season improve. Between Drayton Valley and Edmonton, most of the soils are dark grey or dark grey-wooded. Most of these soils were formed when the tree cover was continuous and they form a transition zone between forest and parkland. The average frost-free period is 75-90 days (agroclimatic zone 3H and 2H).

In the Devon area, the soils south of the river developed from lacustrine material from Lake Edmonton. These chernozemic soils are high in productivity (C.L.I. class 1) and have no limitations for agriculture. The soils north of the river at Devon are grey wooded and dark-grey wooded and have developed on alluvial aeolian material (Brocke 1977, Bowser 1962). They are generally poor for agriculture.

Edmonton City lies on soil composed mainly of Malmo silty clay loam, an eluviated black soil which developed on the lacustrine material of Lake Edmonton. This region also contains pockets of black solonetzic soils associated with the black chernozems. In the vicinity of Edmonton City, the river flows through an area considered to be the best in the province for agriculture, with a growing season usually exceeding 90 days, adequate precipitation, and C.L.I. class 1 soils (Brocke 1977). Most soils in this area are chernozemic, except that solonetzic soils tend to dominate wherever the bedrock is near the surface. Black solonetzic soils are less productive agriculturally than black chernozems. Solonetzic soils are more saline, having a ratio of calcium to other ions of one or less, or having have 15% or more exchangeable sodium (Bowser 1962).

Below Edmonton and as far as the Saskatchewan border, the river flows through the northern edge of the black soil zone . In the stretch from Two Hills to Elk Point, the soils are grey-wooded and are, therefore, less productive. To the southeast of Edmonton City, the Cooking Lake moraine is primarily an area of podzolic or grey wooded soils that are unsuitable for agriculture and designated as C.L.I. classes 5 and 6 (Brocke 1977). Except for this latter area, the soil capacity is designated C.L.I. class 2-3.

2.8 Land Use

Natural vegetation in the Edmonton region is mainly aspen poplar and grasses, with jackpine in the sandy areas, white spruce and balsam poplar along the rivers and larger creeks, and black spruce, tamarack and birch in low, moist areas.

From west to east, the land in the NSR drainage basin is used increasingly for agriculture. Livestock production is the major agricultural activity in the area; most farms are of a mixed type.

The land from Drayton Valley to Devon is perhaps no more than 50% cleared for agriculture, whereas the land east of Devon to the border is mostly cleared. Additionally, the type of agriculture becomes more intensive toward the east, with greater proportions of land devoted to cereal crops and hay.

The agricultural land base in the immediate Edmonton area is gradually becoming urbanized, either as residential/industrial areas within and adjacent to the city limits, or as country residential developments in the rural areas between Edmonton and the fifteen urban communities surrounding the city.

2.9 Water Use

Water from the NSR is used in both consumptive and non-consumptive ways:

Consumptive Uses	Non-Consumptive Uses
Municipal Supply	Cooling (thermal power)
Industrial Supply	Dilution
Agricultural	Apportionment
	Recreation
	Fisheries

Water withdrawals and consumption for the section of the river between Devon and Fort Saskatchewan in 1981 are summarized in Table 2.3.

TABLE 2.3 Summary* of water withdrawals and consumption, North Saskatchewan River, Devon to Fort Saskatchewan, 1981.

Water Use	Quantity Withdrawn ($10^6 m^3 \cdot yr^{-1}$)	Consumption ($10^6 m^3 \cdot yr^{-1}$)
Cooling (thermal power)	414	2.3
Municipal Supply	87	18.2
Oilfield Activities	0.9	0.9
Refineries	9.4	6.9
Petrochemical	17.15	9.9
Metals Industry	4.17	2.4
Food and Beverage	4.75	0.40
Other Industries	11.33	2.76
Agricultural	3.36	3.23
	552	47.0

* from Canadian Resourcecon Ltd. 1982

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The largest water withdrawal from this section of the river is for cooling thermal power generators (414 X 10^6 m^3 · $year^{-1}$ in 1981). The power plant at Clover Bar employs a once-through cooling system and approximately 99% of this water withdrawn is returned to the river. Most of the water used for cooling at the Rossdale generating plant is subsequently fed to the Rossdale Water Treatment Plant and, therefore, becomes part of the municipal water supply. Municipal water supply for the city of Edmonton and outlying towns accounts for the second largest withdrawal (87 X 10^6 m^3 · $year^{-1}$ in 1981). About 80% of this volume is returned to the river after passing through sewage treatment. Average annual total volume of flow in the NSR at Edmonton is 6181 X $10^6 m^3$; water consumption within the Devon to Ft. Saskatchewan section represents less than 1% of this total (Canadian Resourcecon Ltd. et al. 1982).

Reception of waste loads and effluents is a legitimate use of the NSR, because sewage treatment plants and industries are licensed by the province to discharge to the river (see Section 2.10). The licence requirements assume that there is sufficient assimilation capacity in the river, either to dilute wastes or to continue the treatment process by degradation or biological uptake.

There is very little agricultural use of NSR water in the study section of the river. Very small quantities are withdrawn for stockwatering and feedlot operations, for irrigation on sod and tree farms, and for growing alfalfa and vegetables. (Canadian Resourcecon Ltd. et al. 1982).

Alberta is required by the Prairie Provinces Water Board to supply 50% of the natural flow in the NSR at the border with Saskatchewan. This apportionment requirement excludes the effects of the two dams in calculating the required flow, but the reservoirs are used to ensure that the legal flow is attained. Additionally, the Board requires a minimum flow of 100 $m^3 \cdot s^{-1}$ in the river at the border to preserve in-stream uses (Crosby 1982).

Recreation is less important on the NSR than on other water bodies in the vicinity. According to Dykstra (1980), the most frequent water-based recreational activities on the NSR are canoeing and other types of boating. Fishing is of lesser importance. Eighteen recreation access sites are located within the city, and a few unofficial sites, such as Devon bridge, occur along the Devon-Pakan stretch.

Swimming in the river is not popular, probably because of the lack of beaches, the public opinion that the river is of poor quality, and the proximity of several lakes more suitable for swimming. However, a few accessible river sites upstream of the city are popular on warm summer days when algal blooms on lakes are common.

The river is not intensively used for fishing in spite of a fairly high population of goldeye, northern pike, walleye and sauger in the downstream reaches. The river provides the only significant stream fishing opportunity in the eastern half of the NSR basin, but Allan (1984) suggests that limited accessibility, the size of the river, and the public perception that the river is polluted inhibits this recreational use. Two recent studies do suggest that a number of chemical substances occur at low levels in the tissues of fish from the NSR (Alberta Environmental Centre 1983a, 1983b). Although these reports recommend consumption limits on certain sizes of some species of fish, especially for high risk persons (e.g. pregnant women), the concentration of pesticides, PCB's, and mercury were generally considered to be low and to meet safe consumption levels.

2.10 Potential Sources of Pollution to the River

There is a large and growing percentage of the land base devoted to urban and industrial developments in the Edmonton metropolitan area and, to a lesser extent, in a number of smaller population centres in the NSR drainage basin, especially in the central part of the basin where this study has its focus (Fig. 2.2). Within the Edmonton metropolitan region (which covers approximately the stretch of river between the Genesee bridge and the confluence of the NSR with the Redwater River) nearly 17% of the total land area in the NSR watershed was devoted to urban and industrial land uses in 1983 (Edmonton Metropolitan Regional Planning Commission 1983).

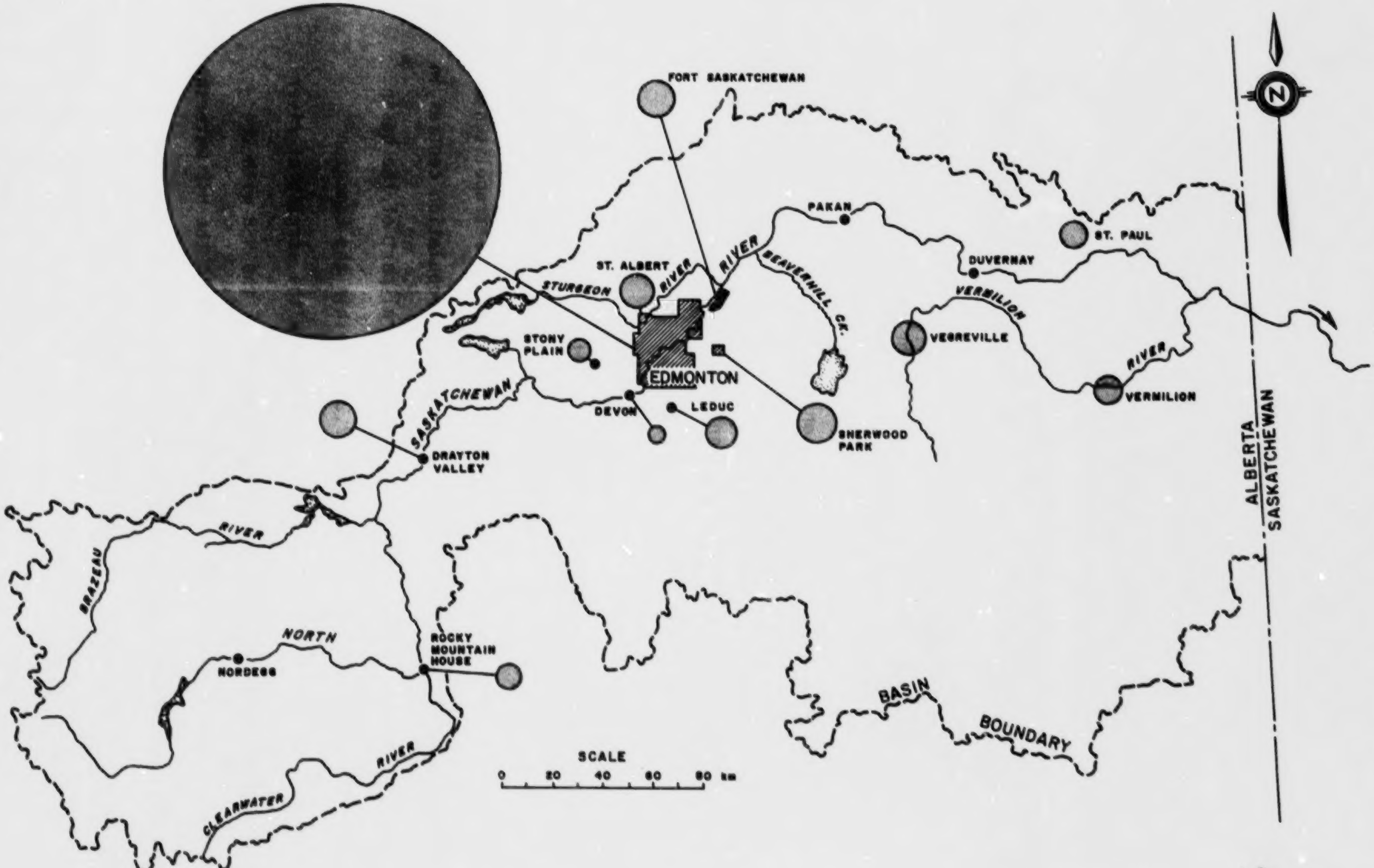
FORT SASKATCHEWAN
ST. ALBERT
STURGEON
RIVER
RIVER
BEAVERHILL CK.
PAKAN
ST. PAUL
DUVERNAY
VERMILION
RIVER
VEGREVILLE
VERMILION
STONY PLAIN
EDMONTON
DEVON
LEDUC
SHERWOOD PARK
SASKATCHEWAN
DRAYTON VALLEY
RIVER
BRAZEAU
NORTH
NORDEGG
ROCKY MOUNTAIN HOUSE
RIVER
CLEARWATER
BASIN
BOUNDARY
SCALE
0 20 40 60 80 km
ALBERTA
SASKATCHEWAN
N

Fig. 2.2 North Saskatchewan River drainage basin showing relative sizes of major population centres.

(Source : ATLAS OF ALBERTA)

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High concentrations of industrial and domestic activity generate large volumes of effluents from industrial plants, sewage treatment plants, and storm and combined sewers (Fig. 2.3). The major effluents in these groups are listed in Section 4.0. Industrial and sewage treatment plant effluents are concentrated as point sources, most of which discharge continuously throughout the year. If such effluents are discharged into rivers, concentrations of pollutants tend to be inversely related to river flow volumes. All municipal and industrial point-source discharges, except storm sewers, are regulated by Alberta Environment. Under the Clean Water Act (Revised Statutes of Alberta 1980, Chapter C-13), these point-sources are granted a License to Operate by the Standards and Approvals Division, and are monitored by the Pollution Control Division.

There are approximately 220 storm water and combined outfalls within the boundaries of the City of Edmonton. Most of these drain directly into the NSR valley; others discharge into ravines (especially Whitemud Creek and Mill Creek) or stormwater retention ponds. Currently, a joint task force from the City of Edmonton and the Province of Alberta is investigating relationships among storm, combined, and sanitary sewage networks. The task force has identified many storm outfalls which may have an impact on river water quality upstream of the City of Edmonton's Rossdale Water Treatment Plant. A report is being prepared on this investigation (L North, pers. comm.).

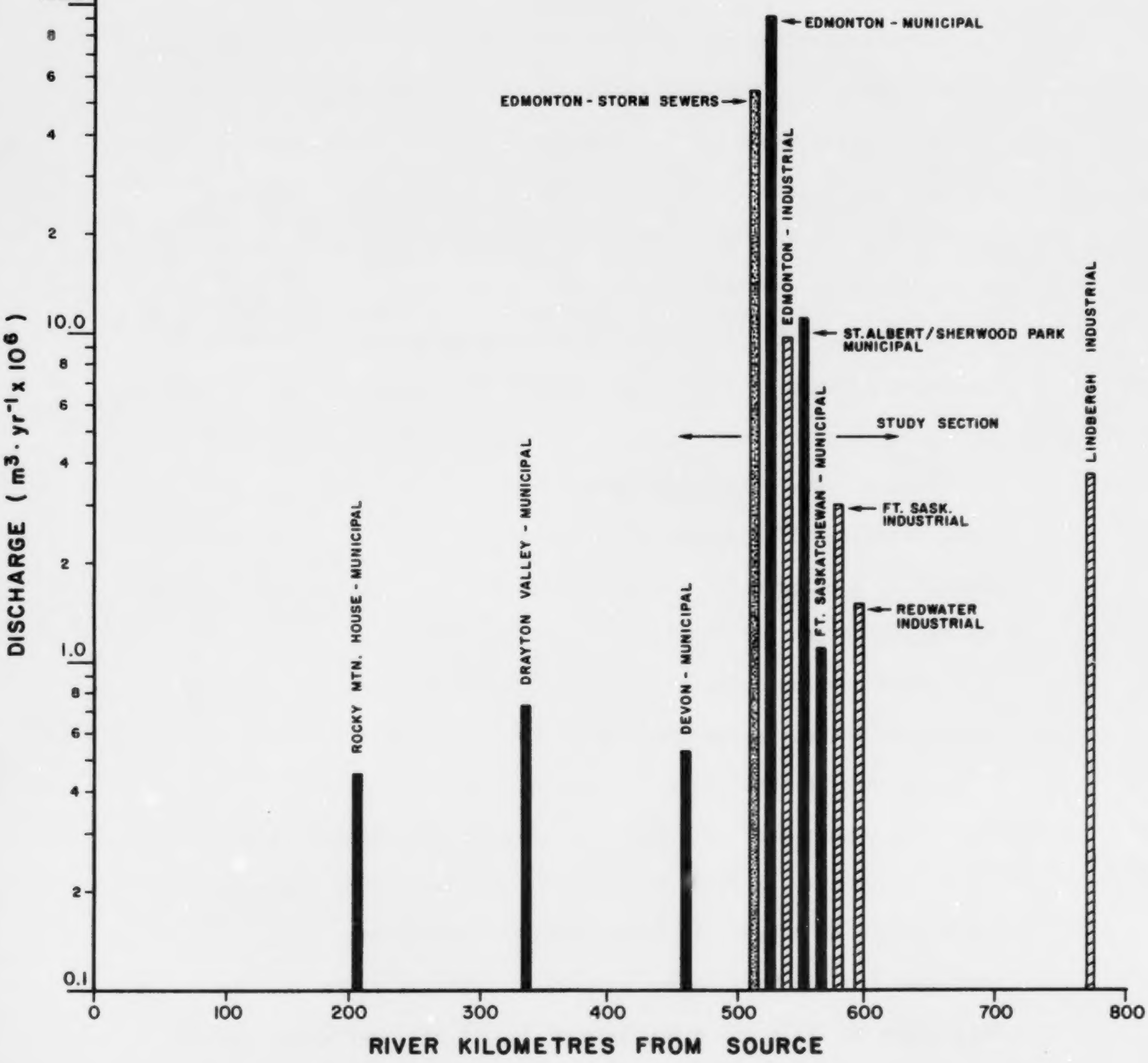

Fig. 2.3 Estimated mean annual discharge from point sources on the North Saskatchewan River during study period, 1982 - 1983.

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The Town of Devon has four stormwater outfalls, all of which drain directly into the NSR (W. Culshaw, pers. comm.). The City of Fort Saskatchewan has 15 stormwater outfalls, seven of which drain to the NSR and eight of which drain into the Ross Creek ravine (F. Daskewech, pers. comm.).

Since the field work for this study was completed, changes have been implemented concerning the treatment and disposal of sewage from a number of smaller population centres around Edmonton. Sewage from Leduc, Nisku, and Beaumont is no longer treated locally and discharged into the Blackmud/Whitemud Creeks drainage system. Instead, sewage from these three population centres now flows to the Gold Bar Wastewater Treatment Plant (GBWTP) via the new Southeast Regional Trunk Sewer. A new Capital Region Sewage Treatment Plant was designed to consolidate the functions of the St. Albert and Bremner sewage lagoons, and to service part of northeast Edmonton. The new plant began to receive sewage from Sherwood Park in November 1984, and from St. Albert in May 1985. The City of Edmonton completed connections to the new plant in June 1985.

Potential sources of pollution in the NSR come not only from identifiable point sources, but also from diffuse sources reflecting various land uses and surface runoff patterns which depend on storm events and spring snowmelt. Potentially polluting substances are carried in runoff from lands used for agriculture and forestry, from paved and roofed areas, and from changed drainage patterns due to diversion and construction. Such diffuse runoff is widespread in the NSR drainage basin; consequently, non-point sources of pollutants are much more difficult to pinpoint. In many instances, the effects from diffuse sources are clearly associated with seasonal runoff or storm events, because there is usually little or no input of pollutants from most diffuse sources during periods of low or no runoff or precipitation.

Superimposed on the spring surface runoff and the flows from storm and combined sewers is the meltwater from the eighteen major snow dumps operated by the City of Edmonton (Fig. 2.4). Effluent volumes from melting snow dumps are variable and diffused over time and space, depending on annual snow accumulation, spring weather conditions, and snow dump locations. The City of Edmonton has maintained these snow disposal sites for several years under a License to Operate issued by Standards and Approvals Division, Alberta Environment. A stipulation of this license is that an environmental testing program be carried out on one of the river sites each year.

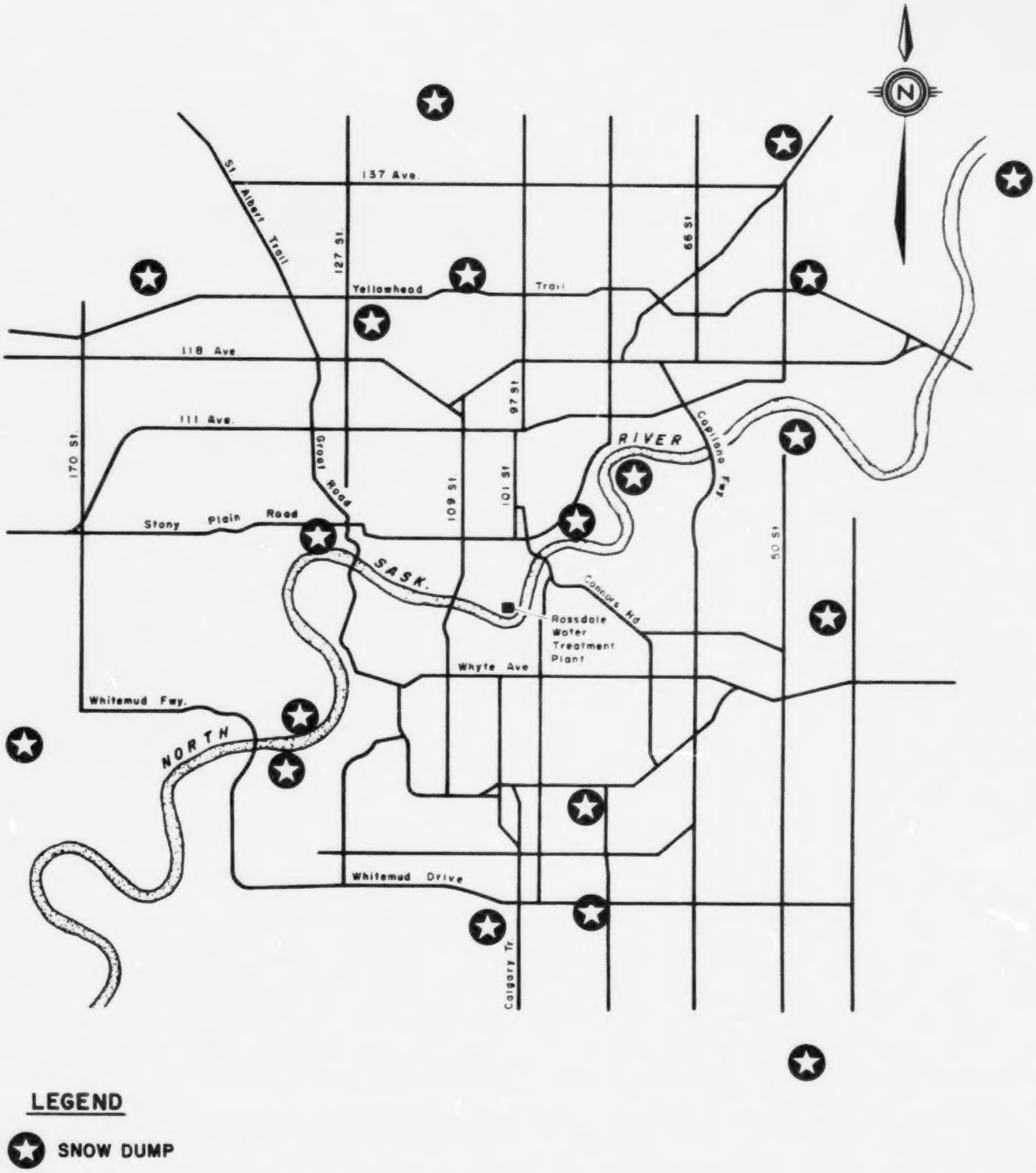
N
St. Albert Trail
137 Ave.
127 St
66 St
Yellowhead Trail
118 Ave.
111 Ave.
170 St.
Groat Road
109 St
97 St
101 St
Capilano Fwy
RIVER
Stony Plain Road
SASK.
Connors Rd
Rossdale Water Treatment Plant
50 St
Whyte Ave
Whitemud Fwy.
NORTH
Whitemud Drive
Calgary Tr.
LEGEND
SNOW DUMP

Fig. 2.4 Arterial map of the City of Edmonton showing the location of snow dumps.

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3.0 MIXING PROCESS IN THE NORTH SASKATCHEWAN RIVER

The mixing process in rivers is a complex phenomenon. It depends on the interaction of many physical and hydrological characteristics unique to each river. A basic knowledge of the mixing process is vital to an understanding of the impacts on water quality of various municipal or industrial effluents entering a river. Although no new investigations of the fates of various municipal or industrial effluents were undertaken during the 1982-1983 survey of the NSR, some mixing studies were carried out previously on the section of the river under study. This part of the report is an overview of the current knowledge of the mixing process in the NSR in the vicinity of Edmonton.

Three in situ investigations of mixing characteristics have been carried out on the North Saskatchewan River. Berner et al. (1971) investigated the lateral mixing patterns of sewage and industrial effluents using the chloride ion (which is present at elevated levels in many effluents) and the fluorescent dye Rhodamine WT as tracers. The chloride ion study was carried out on the 68 km section of the river between the 105 Street Bridge in Edmonton and the Vinca Bridge. Surveys were conducted during the summer of 1971 under "high" flow conditions (500 - 600 $m^3 \cdot s^{-1}$). The Rhodamine WT survey was carried out on the 58 km section between the Gold Bar Wastewater Treatment Plant (GBWTP) and the old Vinca Ferry site.

Three chloride surveys were carried out. The first, conducted from the GBWTP to a point 14 km downstream (Clover Bar Gravel Pits), revealed that a marked transverse gradient existed from south (right bank) to north (left bank) immediately below the GBWTP outfall, and persisted to the end of the run. The second survey, conducted from Fort Saskatchewan to Vinca, revealed that all right bank municipal and industrial inputs from Fort Saskatchewan were poorly mixed laterally by the time the water mass reached Vinca. The third survey, conducted between the old Clover Bar Lagoons and the Fort Saskatchewan Bridge revealed better but still incomplete mixing of the chloride originating from the lagoons. Unlike the other two river sections, this latter mid-section has several strong switchback curves and a stretch of shallow rapids. Vertical mixing appeared to be rapid in all cases.

The surveys carried out with Rhodamine WT confirmed the chloride observations. The authors concluded that any pollutant introduced in the Edmonton area that was not mixed at Fort Saskatchewan would almost certainly not be mixed at Vinca. They also conclude that a pollution gradient, with severity decreasing from right bank to left bank, existed from Edmonton to at least Vinca Bridge.

The second investigation of mixing processes in the NSR was conducted by Pospisilik (1972) during winter low flow and included ice-cover conditions. His research confirmed the poor mixing between Fort Saskatchewan and Vinca but indicated a rather uniform distribution of pollutants at the Fort Saskatchewan Bridge.

The third investigation was also carried out under lower flow conditions (150 - 200 $m^3 \cdot s^{-1}$) in October, 1977, by Beltaos and Anderson (1979). The objective of their study was to determine *in situ* transverse mixing coefficients for the NSR for use in a predictive mixing model. The authors concluded that the NSR displayed very low transverse mixing coefficients which were closer to straight laboratory flume coefficients than those commonly measured in natural streams. They attributed this characteristic to the mild sinuosity of the river.

Consequently, the river is poorly mixed in the section from Edmonton to Vinca, a distance of approximately 70 km, with the exception of the section of river extending approximately 7 km upstream from the Fort Saskatchewan Bridge to the mouth of Pointe aux Pins Creek. Here the river has two consecutive severe bends which cause a localized increase in the transverse mixing coefficient, well above the section average.

The three studies cited are in general agreement that the NSR (as a receiving stream) exhibits poor mixing capability downstream of the City of Edmonton. Effluents discharged within Edmonton and the Clover Bar area have the potential to be mixed by the sharp bends at Point aux Pins Creek although the thoroughness of mixing could be dependent upon river flow at the time of discharge. Discharges into the NSR within and immediately downstream of Fort Saskatchewan are likely to be only partly mixed by Vinca.

4.0 THE STUDY AREA AND STUDY DESIGN

For reasons explained in the introduction, this study concentrated on the section of the North Saskatchewan River (NSR) extending from a location immediately upstream of the Highway 60 bridge at Devon to a downstream location 100 m upstream of the Pakan Bridge near Victoria Settlement (Fig. 4.1). The major industrial effluents entering this section of the NSR are listed in Table 4.1; the municipal sewage effluents are listed in Table 4.2. Major effluent locations are also shown in Figure 4.1. The main historic, geologic, geographic, and related characteristics of the NSR basin and the mixing processes in the study section of the river are described in previous sections on basin characteristics (Section 2.0) and mixing (Section 3.0).

Sampling was done during the 1982 and 1983 field seasons, the latter being extended to include two winter dates in 1984. A list of the eleven regular sampling locations in the NSR for 1982 is given in Table 4.3; for reasons explained below, only six of these locations were sampled regularly in 1983. Study locations are shown in Figure 4.1. The most upstream and downstream locations were chosen to represent relatively unimpacted (control) sites and sites within the recovery zone, respectively. The other nine locations were selected on the basis of their representativeness and value in identifying potential impacts from certain known discharges. At each sampling location, three sampling sites were established: right bank, left bank, centre channel. For two variables (zoobenthos and epilithic

TABLE 4.1 Major Industrial Effluents Entering the NSR in the Vicinity of Edmonton City.

I1. E. L. SMITH WATER TREATMENT PLANT

I2. UNIVERSITY OF ALBERTA (THERMAL)

I3. ROSSDALE POWER PLANT

I4. ROSSDALE WATER TREATMENT PLANT

I5. STELCO

I6. C.I.L.

I7. IMPERIAL OIL REFINERY

I8. SYNCRUDE RESEARCH

I9. TEXACO REFINERY

I10. GULF REFINERY

I11. CELANESE CANADA, UNIROYAL, FIBERGLASS

I12. CLOVERBAR POWER PLANT

I13. ALBERTA CONCRETE, NESBIT

I14. ALBERTA FOOD PRODUCTS

I15. MANVILLE CANADA INC.

I16. SHERRITT GORDON

I17. UNION CARBIDE

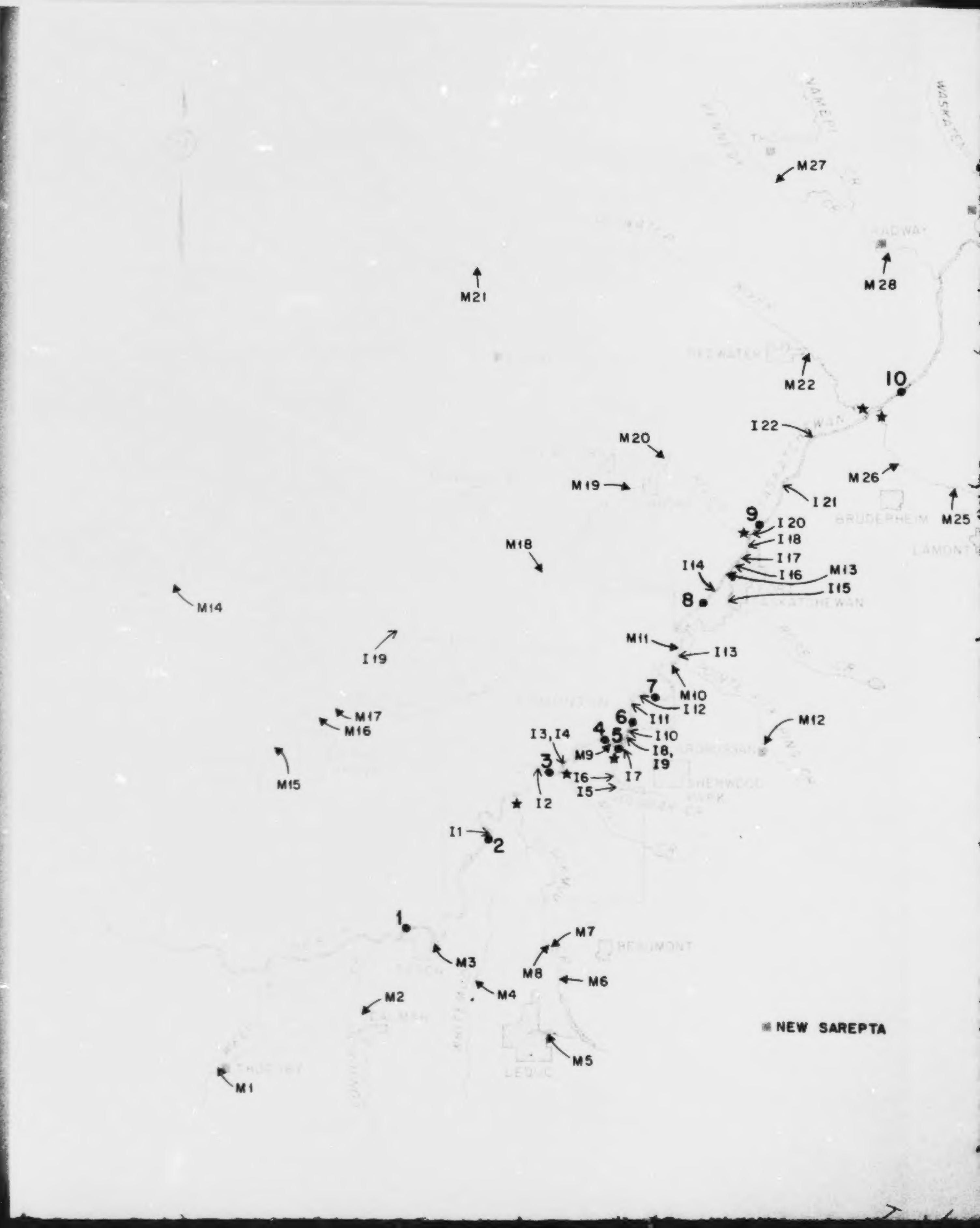
I18. DOW CHEMICAL

I19. ALBERTA CONCRETE, VILLENEUVE

I20. DIAMOND SHAMROCK

I21. SHELL REFINERY, SCOTFORD

I22. ESSO CHEMICALS, REDWATER


M27
REDWATER
M28
M21
M22
10
I22
M20
M26
M19
I21
BRUDERHEIM
M25
LAMONT
9
I20
I18
M18
I17
I16
M13
I14
I15
M14
8
SASKATCHEWAN
M11
I13
I19
M10
7
I12
M17
6
I11
M16
M12
4
5
I10
I3, I4
3
M9
I8, I9
I7
SHERWOOD PARK
M15
I6
I5
I2
I1
2
1
M7
BEAUMONT
M3
M8
M6
M2
M4
CALMAR
NEW SAREPTA
M5
LEDUC
THORSBY
M1

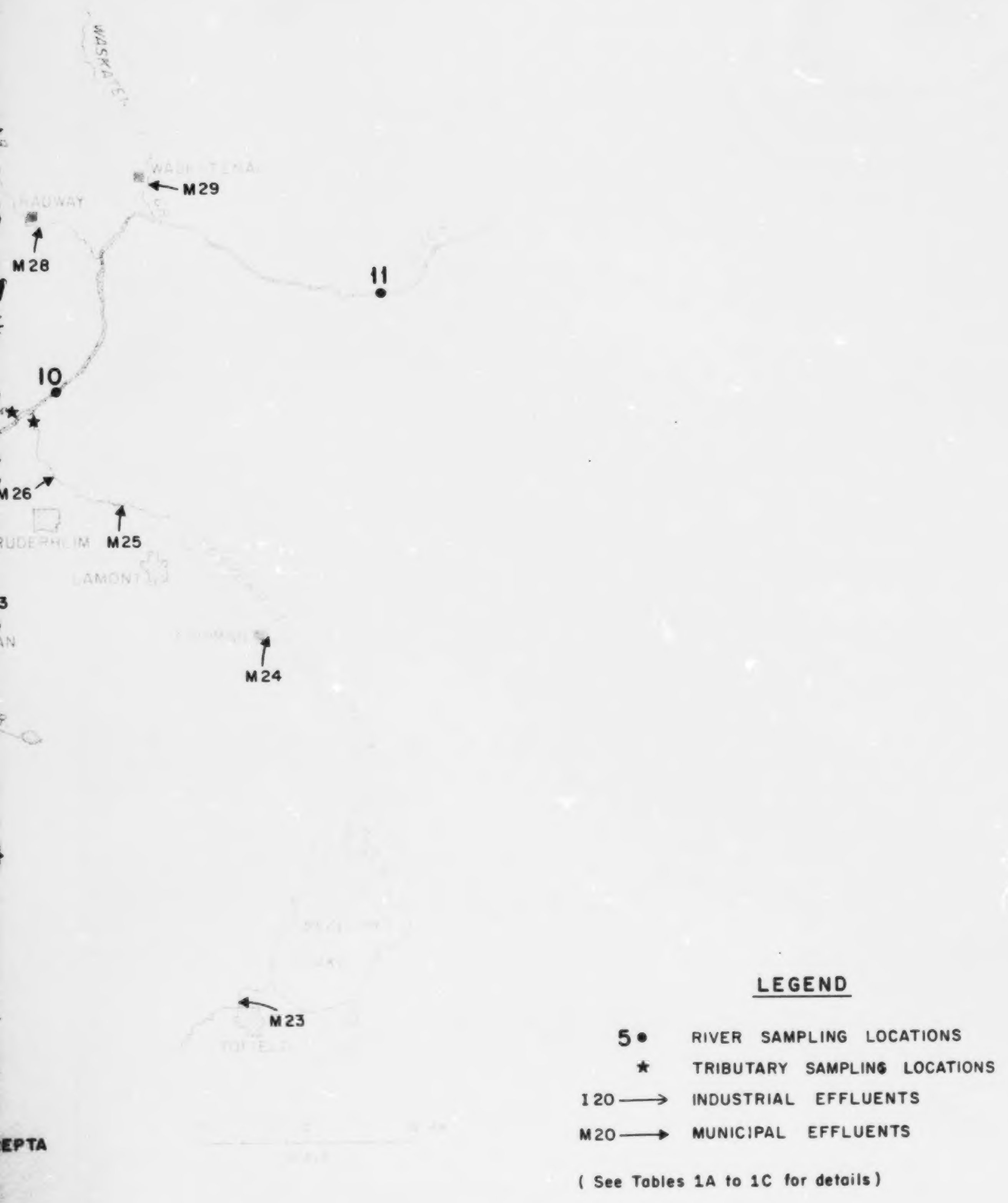

WASKATEN
WASKATENAU
M29
RADWAY
M28
11
10
M26
RUDERHEIM
M25
LAMONT
3
AN
M24
M23
TOFIELD
EPTA
LEGEND
5 ● RIVER SAMPLING LOCATIONS
★ TRIBUTARY SAMPLING LOCATIONS
I20 ⟶ INDUSTRIAL EFFLUENTS
M20 ⟶ MUNICIPAL EFFLUENTS
(See Tables 1A to 1C for details)

Fig. 4.1 North Saskatchewan River study area.

ENVIRONMENT
Pollution Control Division
Water Quality Control Branch

TABLE 4.2 Municipal Sewage Effluents Entering the NSR directly or indirectly in the Vicinity of Edmonton City.

M1. THORSBY
M2. CALMAR
M3. DEVON SEWAGE TREATMENT PLANT
M4. INTERNATIONAL AIRPORT
M5. LEDUC
M6. NEW SAREPTA
M7. BEAUMONT
M8. NISKU
M9. GOLD BAR WASTEWATER TREATMENT PLANT (GBWTP), EDMONTON
M10. BREMNER SEWAGE LAGOONS
M11. ST. ALBERT SEWAGE LAGOONS
M12. ARDROSSAN
M13. FORT SASKATCHEWAN
M14. ONOWAY
M15. STONY PLAIN
M16. PARKLAND VILLAGE
M17. SPRUCE GROVE
M18. MORINVILLE
M19. BON ACCORD
M20. GIBBONS
M21. LEGAL
M22. REDWATER
M23. TOFIELD
M24. CHIPMAN
M25. LAMONT
M26. BRUDERHEIM
M27. THORHILD
M28. RADWAY
M29. WASKATENAU

TABLE 4.3 Regular River Sampling Locations, NSR, 1982 and 1983.

Location Number	Location Name	Relative River Kilometres	Location Description	Selection Criteria
1.	DEVON	0	200 m upstream of Devon Bridge on Highway 60	Control site (background conditions)
2.	E. L. SMITH PLANT*	24	Immediately upstream E.L. Smith water treatment plant	To determine impacts from Devon municipal effluent on water supply
3.	ROSSDALE*	40	100 m downstream of 105th St. Bridge-Rossdale	To determine impacts from large separate storm sewers on water quality for Rossdale Water Treatment Plant
4.	50TH STREET FOOTBRIDGE	51	100 m upstream of 50th St. Footbridge	To identify impacts from large combined storm sewers before Gold Bar Wastewater Treatment Plant
5.	RUNDLE FOOTBRIDGE*	52	100 m downstream of Rundle Park Footbridge	To identify impacts from Gold Bar Wastewater Treatment Plant prior to industrial discharges
6.	BEVERLY BRIDGE	55	200 m downstream Beverly Railway Bridge	To incorporate effects of industrial - part refinery discharges
7.	CLOVER BAR*	61	4 km downstream of Celanese downstream of Clover Bar	To incorporates all municipal and industrial effluents from Edmonton
8.	FORT SASKATCHEWAN BRIDGE	79	200 m upstream Fort Saskatchewan Railway Bridge	Downstream of St. Albert and Bremner lagoons
9.	STURGEON*	89	Downstream of confluence with Sturgeon River	To include effects of Fort Saskatchewan industrial and municipal effluents
10.	VINCA BRIDGE	112	500 m downstream of Vinca Bridge	To reflect all major inputs; also robot monitor location
11.	PAKAN BRIDGE	163	100 m upstream of Pakan Bridge	Site reflecting complete mixing in the river; also a routine monitoring site

* designates locations not sampled in 1983

chlorophyll-a), only the left-bank and right-bank sites were used. For some chemical variables at each of the two most upstream locations, samples from the three sites were combined into a simple composite sample on each sampling occasion.

Although there are dams, agricultural and oilfield developments, and some population centres (Rocky Mountain House and several smaller centres) upstream of Devon, the NSR at the Devon bridge is considered relatively unimpacted by domestic and industrial waste effluents (unpublished data, Alberta Environment). The first sampling location is upstream of the Devon Sewage Treatment Plant, near an Alberta Environment River Water Quality Monitoring Network station.

The mixing studies reviewed in the previous section have indicated incomplete mixing as far downstream as Vinca bridge on Highway 38. However, it is assumed that mixing is complete most or all of the year at the Pakan Bridge near Victoria Settlement. Another reason for selecting this as the lower sampling location is that it is also a routine station of the River Water Quality Monitoring Network.

For study design purposes and for reasons noted in the introduction (Section 1.0), the river was considered to have three components: the flowing water component, the river bed or sediment component, the biological component.

The flowing water component included the water and its non-living dissolved and suspended load. Table 4.4 summarizes the chemical variables measured in 1982 and the sampling dates for that year; some biological and physical variables sampled on the same dates are also included in this table. Table 4.5 is a summary of the water component

TABLE 4.4 Variables for which analyses were performed, NSR, 1982 field season.

PHYSICAL

- Temperature (Field)
- Depth (Field)
- Flow

MAJOR IONS & RELATED

- pH
- Conductivity (Field, Lab)
- Dissolved Oxygen (Field)
- Calcium
- Hardness
- Sodium
- Potassium
- Silica
- Chloride
- Fluoride
- Sulphate
- Carbonate
- Bicarbonate
- Alkalinity
- TDS
- T.R.
- F.R.
- NFR
- BOD
- COD
- TOC
- DOC
- TPC
- DIC

NUTRIENTS

- Phosphorus (total)
- Nitrogen (total)
- Ammonia (total)
- Nitrite
- Nitrite-Nitrate
- TKN
- TON

METALS

- Mercury
- Cobalt
- Copper
- Nickel
- Cadmium
- Lead
- Zinc
- Beryllium
- Aluminum
- Arsenic
- Selenium
- Chromium
- Manganese
- Molybdenum
- Vanadium
- Iron

ORGANICS

- PCBs
- Phenols
- Pesticides & Herbicides
  - BHC
  - Aldrin
  - O.P., D.D.T.
  - P.P., D.D.T.
  - 2, 4-D
  - 2, 4,S-T
  - Dieldrin
  - M.C.P.A.
  - Endrin
  - Dursban
  - Heptochlor
  - Hexachlorobenzene
  - Lindane
  - Tordon
  - Methoxychlor
  - Diazinon
  - Methylparathion
  - Dimethoate
  - Heptochlor expoxide
  - Malathion

BIOLOGICAL

- Coliforms
- Fecal Coliforms
- Fecal Streptococci
- Standard Plate Count

SAMPLING DATES

18-19/05/82*
01-02/06/82*
15-16/06/82*
29-30/06/82*
13-14/07/82*
27-28/07/82*
10-11/08/82*
24-25/08/82**
08-09/09/82**
05-06/10/82
19-20/10/82**
02-09/11/82

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* selected analyses (see Table 5.2) by City of Edmonton on dates noted.

** analyses (see Table 5.2) by AEC, Vegreville, on dates noted.

TABLE 4.5 Variables for which analyses were performed, NSR, 1983 field season.

PHYSICAL

Temperature (Field)
Depth (Field)
Flow

MAJOR IONS & RELATED

pH
Conductivity
(Field, Lab)
Dissolved Oxygen
(Field)
Calcium
Magnesium
Hardness
Sodium
Potassium
Silica
Chloride
Fluoride
Sulphate
Carbonate
Bicarbonate
Alkalinity
TDS
T.R.
F.R.
NFR
Cyanide
BOD
COD
DIC
DOC
TPC

NUTRIENTS

Phosphorus (total)
Nitrogen (total part.)
Ammonia dissolved
Nitrite
Nitrite-Nitrate
TKN

METALS

Mercury
Cobalt
Copper
Nickel
Cadmium
Lead
Zinc
Beryllium
Aluminum
Arsenic
Selenium
Chromium
Manganese
Molybdenum
Vanadium
Iron

ORGANICS

PCBs*
Phenols

PRIORITY POLLUTANT SCAN*

Extractables-79 compounds
Purgeable - 24 compounds
Chlorinated Pesticides
Chlorinated Herbicides
Organophosphorus Pesticides
Organonitrogen Pesticides

SEDIMENT PHASE*

Priority Pollutant Scans
Extractables (79)
Chlorinated Pesticides
Chlorinated Herbicides
PCBs
Metals

BIOLOGICAL

Coliforms
Fecal Coliforms
Fecal Streptococci
Standard Plate Count
Chlorophyll
Benthic Algae
Plankton

SAMPLING DATES

17-26/05/83	01-02/06/83	14-16/06/83
28-29/06/83	13-14/07/83	03-04/08/83
23-24/08/83	20-21/09/83	12/10/83
15-17/11/83	01-02/02/84	01-02/03/84

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* once only, 5-6 October, 1983

sampling dates and variables measured in 1983 including, as in 1982, some biological and physical variables on the same dates. The changes in variables measured from 1982 to 1983 were due to some difference in the analytical facilities used and to some changes in analytical techniques and detection limits made to comply with conditions determined for the NSR in 1982. For example, the City of Edmonton Laboratory detection limits for nitrogen compounds were too high for the low concentrations found at upstream sites and, consequently, many 1982 results are listed as "not detectable". Analyses for nitrogen compounds were done by the Alberta Environmental Centre (AEC) Laboratory in 1983.

There were also some differences in the sampling regimes for 1982 and 1983. In 1982, eleven locations comprising 33 sites were sampled; each location included a left-bank, a right-bank, and a centre-channel site. The 1982 study was planned as a broad characterization of the study area; all sampling sites were in the mainstem of the NSR. The intention was to assess the interpretive value of sites, bank-to-bank (lateral) variations in water quality, and longitudinal and seasonal variations in water quality.

Prior to the 1983 sampling season, the preliminary results from 1982 were reviewed and the sampling program was revised to achieve the broad objectives of the study most expediently. Five sampling locations were dropped in 1983; these locations were considered to be redundant in defining zones of impact or recovery. In order to assess the impacts of a number of point-source discharges, several industrial and municipal effluents and a number of tributaries entering the NSR within the study area were sampled in 1983; these are summarized in Table 4.6. The physical and chemical variable measured at the point-source discharge sites were essentially the same as for the mainstem NSR sites for 1983.

Flow data are needed before calculating loading from various point sources. For the NSR and for several tributaries in the study area, flow data were obtained from records published by the Water Survey of Canada (Environment Canada 1983, 1984a, 1985). The mainstem NSR station is at the Low Level Bridge in the City of Edmonton; tributary stations are maintained at Whitemud, Blackmud, and Beaverhill creeks, and at Redwater and Sturgeon rivers.

The riverbed sediment component was not investigated extensively in this study. A single survey was conducted on 5-6 October, 1983; sediment samples collected were analyzed for certain organics and metals for the purpose of determining the interpretive value of such data and assessing the need for additional data collection. Metal analyses included lead, copper, nickel, arsenic, cadmium, mercury, zinc, and chromium; organics included priority pollutant scans, extractables (79), chlorinated pesticides, chlorinated herbicides, and PCBs.

Three aspects of the biological component were investigated: the bacteria in the flowing water; chlorophyll-a in the flowing water and on the surface of riverbed material; the invertebrate community living in and on the riverbed material. The bacterial investigations were

TABLE 4.6 Summary of sampling events and variables assessed in tributaries and effluents to the NSR, 1983.

Tributary Streams	No. of samplings	Variables
Whitemud Creek	9	Same as NSR sites 1983
Mill Creek	4	Excluding: - Benthic algae chlorophyll-a
Fulton Creek	4	
Gold Bar Creek	7	- Priority pollutants
Sturgeon River	9	- Pesticides
Redwater River	9	- Herbicides
Beaverhill Creek	6	
Municipal Effluents		
Devon STP	10	Same as NSR sites 1983
GBWTP	10	Excluding: - Priority pollutants
Bremner Lagoons	5	- Pesticides
St. Albert Lagoons	7	- Herbicides
Fort Sask. Lagoons	8	- Chlorophyll-a
Industrial Effluents		
Imperial Refinery	2	Same as NSR sites 1983
Texaco	2	Excluding: - Chlorophyll-a
Gulf	2	
Celanese, Fiberglas, Uniroyal	2	
Alberta Food Products	2	
Union Carbide	2	
Sherritt Gordon	2	
Dow Chemical	2	
Diamond Shamrock	2	
Esso Chemical	2	

conducted in both 1982 and 1983 on the same schedule as the chemical sampling and included mainstem NSR sites, tributaries, and municipal effluents. A summary of bacterial analyses performed and sampling dates is given in Tables 4.4 and 4.5. The main purposes of this part of the overall study were to provide a general characterization of the bacterial flora in the section of the NSR under study, to provide data for comparison with Alberta Surface Water Quality Objectives, and to provide information useful in determining point sources.

The chlorophyll-a survey was conducted in 1983 only, and on the same schedule as the chemical sampling (Table 4.5). The flowing-water chlorophyll-a provides an estimate of the biomass of potamophytoplankton (free-floating microscopic algae); the chlorophyll-a from the surface of bottom materials gives an estimate of the biomass of epilithic algae growing on rocks and other submerged surfaces. Developmental patterns in these two forms are helpful in appraising growth inhibition or enhancement due to point-source inputs of nutrients and other dissolved substances, and such factors as temperature changes, sedimentation, and light penetration. The advantage of epilithic algae over potamophytoplankton is that, because they remain fixed to the substrate, the epilithic algae reflect the accumulated effects of dissolved substances and changing conditions over a long time period. As noted in the introduction, a macrophyte survey was not included in the 1982-1983 study because no extensive or persistent macrophyte development had been observed in the NSR.

A rather extensive zoobenthic monitoring program was undertaken in 1982 to complement the monitoring of chemical and physical variables. Chemical analyses permit the detection and quantification of a wide range of pollutants and their point sources in a river, but they reflect conditions at the time of sampling only. Zoobenthic organisms are exposed to fluctuations in water quality over an extensive period of time; therefore, the zoobenthos tends to act as an integrator of changes in water quality over time through a complex of responses reflecting tolerance limits. The rather low mobility potential of most zoobenthic taxa makes this group more useful as an indicator of water quality than the more mobile fish or zooplankton, which can move away from adverse conditions in a section of a river. Because of this integrator quality and because of the relative longevity of most zoobenthic taxa (several months to two or more years), it was neither necessary nor practical to sample zoobenthos with the same frequency that water samples were taken for chemical analysis. Details of the zoobenthic part of the biological component are treated in Part Two of this report.

5.0 GENERAL METHODS

5.1 Field Methods

For water chemistry, bacterial, and chlorophyll sampling during the open-water season, mainstem river and tributary sites were reached by means of an inboard-motor river jet boat. Each sampling event took two days: the first day included upstream sites (Devon to Beverly Bridge); the second day included downstream sites (Edmonton Cloverbar to Pakan).

All mainstem river and tributary samples for water chemistry analysis were collected with a stainless steel sampling bucket as surface grab samples. Each sample was subsampled directly into a specially prepared sample bottle, preserved, and handled according to the recommended procedures of the Research Laboratory, Alberta Environmental Centre (AEC), Vegreville. Field filtration was not performed on samples for dissolved nutrients. Water samples for chemical analysis were kept on ice in coolers in the field and transported to the Research Laboratory, AEC, within 24 hours. As noted below, a few variables were analyzed elsewhere in 1982.

In all cases, industrial and municipal effluent samples were collected as grab samples from the final effluent stream, either at the river outfall location if access was possible, or from a plant access point. The effluent from the Gold Bar Wastewater Treatment Plant (GBWTP) was collected as a 24-hour composite sample from the final effluent using a Manning Stationary Composite Sampler model no. S-5200-0-C-0-A-0 (S. Banerjee, pers. comm.).

Measurements of water temperature, specific conductance, and dissolved oxygen were taken with a Model 4041 Hydrolab meter at each sampling site on all sampling occasions except one, when sampling was done from bridges during the ice-flow period. The Hydrolab meter was calibrated prior to each sampling trip. The NAQUADAT codes for field variables measured are: depth - 97551F; temperature - 02065F; dissolved oxygen - 08102F; specific conductance - 02042F (Environment Canada 1984b). In the latter part of November during periods of ice flow, samples were collected from bridge locations wherever possible by lowering a stainless steel bucket into the river from the bridge walkway. Bridge sampling locations included Devon, 105th Street, 50th Street Footbridge, Beverly, Fort Saskatchewan, Vinca, and Pakan bridges. Mid-winter samples (February and March, 1984) were collected from left- and right- bank sites for each mainstem location by walking a safe distance from shore on the ice, drilling a hole with an ice auger, and collecting a sample in a stainless steel bucket.

As outlined in the study design, eleven mainstem NSR locations were sampled in 1982, and six in 1983 (see Table 4.3 and Fig. 4.1). Discrete samples were collected for analysis from each of three sites at each location (i.e. left-bank, right-bank, and centre-channel sites). In 1982, however, samples for the three sites at each of the two upstream locations (Devon and E. L. Smith) were combined into composite samples for analysis because preliminary data showed little lateral difference. Discrete samples from each site at the other nine locations were analyzed separately.

Sediment samples were collected for chemical analysis only once (5 and 6 October, 1983). Samples were collected at the six mainstem NSR sites sampled routinely during 1983 for other variables. Samples were collected by means of a stainless steel "air-lift" sampler using nitrogen gas. The sediment was sampled to a depth of 10 cm, governed by the depth of the sampler collector cup. The samples were allowed to settle for 24 h, after which the supernatant water was removed and the sediment samples transferred to solvent-washed, oven-dried, wide-mouth amber glass jars with teflon liners under the lids. Samples were kept in a cooler or refrigerator at 2 to 5°C and transported to the Alberta Environment Centre (AEC), Vegreville, as soon as possible.

Samples for the analysis of organic compounds were collected, preserved, and handled according to procedures outlined in Longbottom and Litchenberg (1982). Water samples for trace organics and pesticide chemicals were collected directly into solvent-washed, oven-dried amber glass bottles with aluminum-lined caps.

Samples for bacterial analysis were collected directly into one-litre sterilized polypropylene bottles at a depth of one meter; the sample bottles were held in a special stainless steel sampling cradle which permitted sampling at the appropriate depth.

Samples for potamophytoplankton chlorophyll-a analysis were taken from surface grab samples on the regular sampling dates in 1983 which are listed in Table 4.5.

Samples for epilithic algal chlorophyll-a analysis were collected from left-bank and right-bank sites at each sampling location in 1983. At each site, ten stones were collected randomly on a transect perpendicular to the shoreline. Each stone was scrubbed entirely with a small, hard-bristled brush and rinsed with distilled water until all visible epilithic growth was removed. The volume of slurry obtained from the scrubbing of all stones collected from one sampling location was recorded, after which the slurry was homogenized. From each sample, one 50 ml subsample was filtered onto a Whatman GFC filter; powdered magnesium carbonate was added during filtration. Filters were wrapped in aluminum foil and stored on ice until returned to the laboratory.

Field methods used in the collection of zoobenthic samples are given in Part Two of the report.

5.2 Laboratory Methods

In 1982, most chemical analyses were carried out by the Research Laboratory, Alberta Environmental Centre (AEC), Vegreville. In 1983, all chemical analyses were performed by AEC. The NAQUADAT codes for analyses performed by AEC are summarized in Table 5.1 (Environment Canada 1984b). In 1982, some analyses were performed by the City of Edmonton Laboratory or by the Pollution Control Division, Alberta Environment, Edmonton. The NAQUADAT codes for 1982 analyses other than those done by AEC are given in Table 5.2. The NAQUADAT Dictionary of Parameter Codes (Environment Canada 1984b) summarizes the analytical methods.

TABLE 5.1 Summary of Analytical Methods (AEC, 1982-1983)

Variable	NAQUADAT Code	Detection Limit ($mg \cdot L^{-1}$)
pH	10301L	
Specific Conductance $uS \cdot cm^{-1}$	02041L	
Non-Filterable Residue	10407L	2.0000
Residue, Total	10474L	0.0100
Total Dissolved Solids	00205L	
Alkalinity, T. as $CaCO^3$	10101L	5.0000
Hardness, T. as $CaCO^3$	10602L	5.0000
Bicarbonate	06201L	5.0000
Carbonate	06301L	5.0000
Calcium	20110L	1.0000
Magnesium	12102L	1.0000
Sodium	11103L	1.0000
Chloride	17203L	1.0000
Sulphate	16306L	5.0000
Potassium	19103L	0.2000
Fluoride	09107L	0.0500
Nitrogen, T. as N	07601L	0.0500
Nitrogen Ammonia, Diss. as N	07562L	0.0500
Nitrogen NO_3 + NO_2, Diss. as N	07105L	0.0500
Nitrogen NO_2, Diss. as N	07205L	0.0010
Nitrogen T. Kjeldahl as N	07021L	0.0500
Nitrogen T. Partic. as N	07906L	0.0100
Phosphorus, T. as P	15421L	0.0060
Silica Reactive	14102L	0.5000
Carbon Inorganic, Diss.	06154L	1.0000
Carbon Organic, Diss.	06107L	0.4000
Carbon Partic., Diss.	06905L	0.0100
Phenolics	06537L	0.0020
Cyanide	06608L	0.0020
Mercury, T.	80015L	0.0001
Cadmium, T.	48009L	0.0010
Arsenic, T.	33005L	0.0002
Copper, T.	29009L	0.0010
Lead, Ext.	82302L	0.0030
Manganese, T.	25003L	0.0080
Nickel, T.	28009L	0.0010
Zinc, T.	30009L	0.0010
Selenium, T.	34005L	0.0002
Molybdenum, T.	42009L	0.0010
Chromium, T.	24009L	0.0010
Cobalt, T.	27009L	0.0010
Aluminum, Ext.	13306L	0.0200
Beryllium, Ext.	04304L	0.0010
Vanadium, T.	23009L	0.0020
Iron, Ext.	26304L	0.0020
Chemical Oxygen Demand (COD)	08304L	5.0000
Biochemical Oxygen Demand (BOD)	08202L	1.0000

TABLE 5.2 Summary of analytical methods (1982-1983)

Bacterial Analyses (1982-83 by EPS, Environment Canada)

Variable	Code
Total Coliforms	36001L - 36002L
Fecal Coliforms	36011L - 36012L
Fecal Streptococci	36102L
Standard Plate Count	36910L

Chemical Analyses (1982, AEC except where noted)

Variable	Code
Phenols *	06536L
Total Phosphorus as P **	15406L
COD *	08301L
NO_2-N *	07206L
NH_3-N *	07503L
TKN *	07001L
BOD *	08202L
BHC	18814L
Aldrin*	18130L
O,P,D, DDT*	18005L
P,P, DDT	18000L
2,4-DB	18550L
2,4-D	18500L
2,4,5-T	18510L
Dieldrin*	18150L
MCPA	18520L
Endrin*	18140L
Dursban	18210L
Heptachlor*	18040L
Hexachlorobenzene	17811L
Lindane*	18070L
Tordon	18600L
Methoxychlor*	18030L
Diazinon	18270L
Methylparathion*	18245L
Dimethoate	18340L
Heptachlor Expoxide*	18045L
Malathion	18250L
PCBs*	17801L

* City of Edmonton until 10-11 August, 1982
** Pollution Control Division, Alberta Environment

Except for the analysis for total phenolic materials, which used the 4-amino-antipyrene colorimetric method (NAQUADAT Code 06532L), the U.S. Environmental Protection Agency (EPA) analytical protocol procedures were employed in the analyses for organic compounds. Generally, qualitative screening for target compounds used relative retention times on gas chromatography (GC) and relative abundances of characteristic ions from the gas chromatography/mass spectrometry (GC/MS) data of components of the extracts. The final identifications and quantifications were accomplished by comparison with full reference spectra and/or comparison of the sample spectral response with that of an appropriate internal standard. Because the analyses of target compounds (Table 5.2) were emphasized in the study, the study results do not exclude the presence of other organic compounds not analyzed for specifically.

Analyses for organics in sediments were done by AEC; analyses for metals in sediments were performed by the Inland Waters Directorate laboratory of Environment Canada at Burlington, Ontario.

All bacterial analyses were conducted by the Environmental Protection Service, Environment Canada, Edmonton. The NAQUADAT codes for these analyses are summarized in Table 5.2.

Potamophytoplanktonic and epilithic chlorophyll-a analyses were carried out by the Pollution Control Division, Alberta Environment, Edmonton; NAQUADAT codes for these variables were 06715L and 06721L. respectively.

Laboratory methods used in the analysis of zoobenthic samples are given in Part Two of this report.

5.3 Statistical Methods

In order to conduct comparative analyses and difference testing, it was necessary to reduce the measurements for each variable to a measure of central tendency. Three statistics commonly employed for this purpose are the mean, the median, and the mode. In a perfectly normal distribution, mean, median, and mode coincide, but normal distributions are seldom encountered in water quality data sets due to the variable influences of hydrological and biological forces with time (Helsel 1983). Because concentration medians may be more representative of central tendency than the means in skewed distributions, and because several powerful, non-parametric tests can be used to test the differences between the medians of non-normal data sets (Elliott 1977), the 1982-1983 data for different sites and locations were summarized as median concentrations (i.e. 50th percentile: Zar 1974).

Most paired chemical data in this study were tested statistically using the Wilcoxon matched-pairs signed-rank test (Siegel 1956), which is a non-parametric test for the comparison of median values. The two-tailed test was used, and differences were considered significant at the 0.05 probability level. Although statistical difference testing for non-conservative constituents along a river section may not always be exhaustive, it is used in this analysis to identify the minimum level of significant spatial or temporal change.

5.4 Interpretation

To aid in interpretation, historical chemical and bacteriological data for the two regular Alberta Environment River Water Quality Monitoring Network stations at Devon and Pakan were used in some sections as an additional information source, especially for variables not investigated extensively in the course of this study.

River water quality was assessed by comparing measured values for different variables with Alberta Surface Water Quality Objectives (ASWQO), or sometimes with other objectives or guidelines when there were no ASWQO. Values higher than those stated in the ASWQO were treated as exceedences. However, two important conditions governing the application of the ASWQO should be kept in mind when assessing actual measured values: 1) the Objectives "apply to surface waters except in areas of close proximity to outfalls"; 2) the Objectives do not apply "where the natural water quality of a lake or river does not meet some of the suggested limits" (i.e. the natural levels may exceed the proposed criteria) (ASWQO, Alberta Environment 1977).

6.0 TEMPERATURE

The temperature regime in flowing surface waters is primarily dependent upon climatic and geographic conditions. Latitude, elevation, season, time and type of day, and flow velocity all affect river water temperature. Surface water temperatures are also modified by human activities; for instance, waste heat may be transferred to receiving waters from industrial discharges resulting in the elevation of water temperature above ambient levels.

Flowing waters do not usually exhibit the vertical stratification that characterizes many standing waters, although some lateral or other differences may develop due to variations in flow velocity. For example, backwaters or nearshore regions of rivers may have higher temperatures than the mainstream during the heat of summer, but will cool faster and freeze over first as winter sets in.

In this investigation, temperature was measured routinely at the same locations and sites, and on the same dates selected for sampling major chemical variables (Tables 4.3, 4.4, and 4.5), except that discrete temperature readings were made at centre-channel, left-bank and right-bank sites for the Devon and E.L. Smith locations, whereas composite samples were collected for chemical variables.

6.1 Results and Discussion - Temperature

A summary of median NSR temperatures for the 1982 and 1983 field seasons is included with the dissolved oxygen data in Figure 7.1 (Section 7.1). Within the study section of the NSR, water temperatures ranged from lows near 0.0°C in winter under ice cover to highs near 25°C in August, 1983. Longitudinal variations in water temperature at left-bank and right-bank sites for selected dates in 1982 are shown in Figure 6.1. Site-to-site variations in temperature were partly due to natural diurnal temperature progressions (sampling and temperature measurements proceeded in a downstream direction on a given day and so all temperatures were not measured simultaneously) and partly due to effluents at non-ambient temperature entering the river from tributaries, industries, or municipal facilities. Based on continuous hourly temperature data collected at Vinca in 1982 (Robot Monitor Program, Alberta Environment), water temperatures increased by as much as 1.0°C between 10.00h and 16.00h, the approximate time period over which sampling was done on a given day. Therefore, site-to-site temperature comparisons should take this possible source of variation into account.

A comparison of paired temperature data throughout the study period for Devon and Pakan shows that temperatures at Pakan averaged 0.9°C higher than temperatures at Devon (Table 6.1).

There was a consistent peak in water temperature at Clover Bar, right-bank site (Fig. 6.2). This site is located below the City of Edmonton Clover Bar Power Plant, which discharges heated condenser water into the NSR. Table 6.1 is a comparison of data from the Clover Bar right bank and Beverly Bridge centre-channel sites, the latter of which is located upstream of the power plant and is assumed to

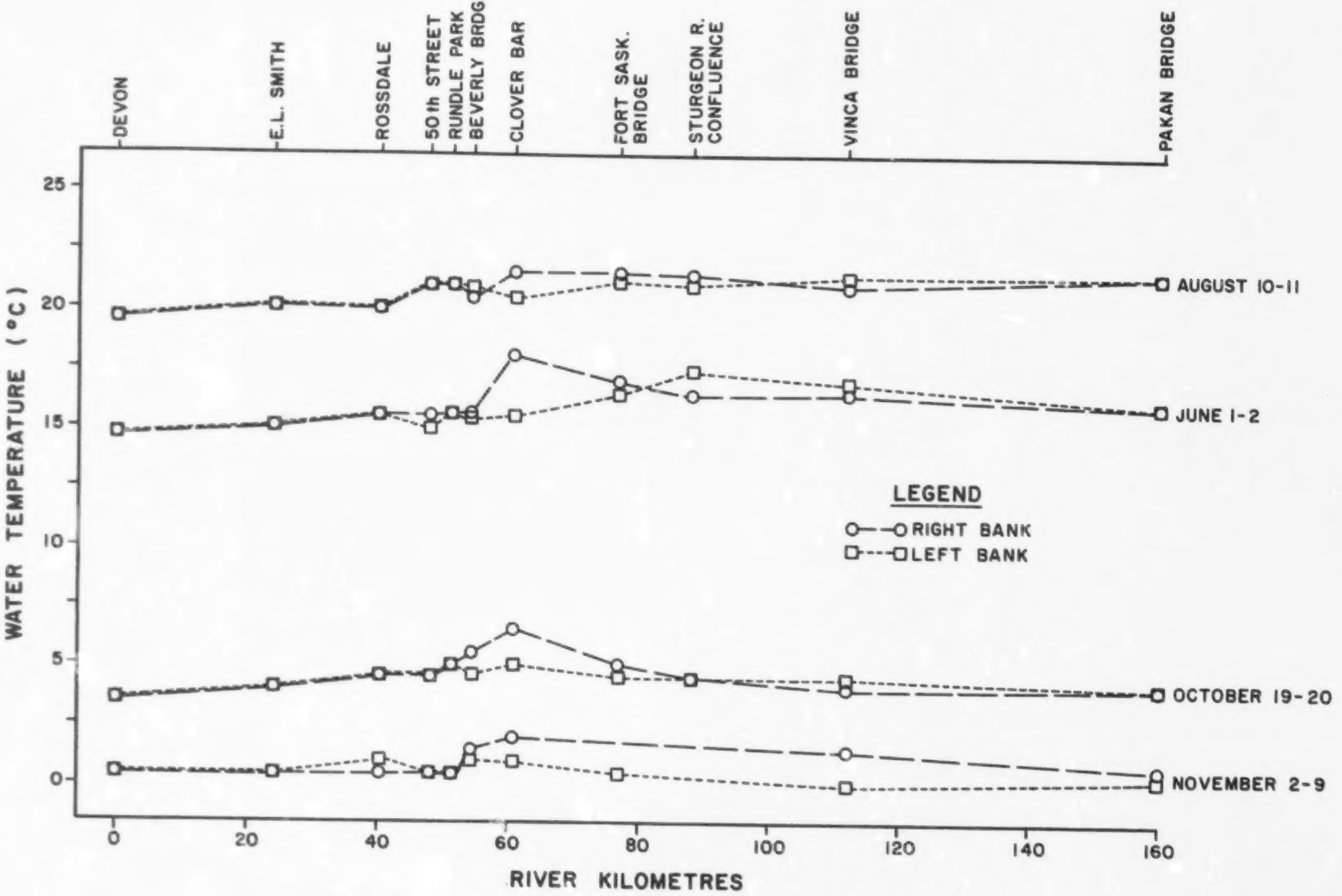

Fig. 6.1 Water temperatures at 11 locations in the North Saskatchewan River on 4 dates, 1982.

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TABLE 6.1 Temperature summary in °C (means for left-bank, centre-channel, and right-bank sites) for the North Saskatchewan River, Devon and Pakan locations, 1982-1983.

DEVON			PAKAN			
1982 DATE	(TIME)	x	DATE	(TIME)	x	ΔT
19/05	1045	11.0	19/05	1005	--	--
01/06	1000	14.8	02/06	1220	15.9	+1.1
15/06	1100	18.3	16/06	1150	19.5	+1.2
29/06	1030	15.0	30/06	1100	16.5	+1.5
13/07	1045	17.5	14/07	1115	19.0	+1.5
27/07	1005	18.3	28/07	1120	20.0	+1.7
10/08	1030	19.5	11/08	1205	21.5	+2.0
24/08	1040	18.5	25/08	1140	17.0	(-1.5)
08/09	1015	15.5	09/09	1115	16.5	+1.0
05/10	1030	7.4	06/10	1135	7.5	+0.1
19/10	1130	3.5	20/10	1250	4.0	+0.5
02/11	1045	0.5	09/11	1135	0.4	(-0.1)
1983						
17/05	1300	9.4*	26/05	1800	15.2*	---
31/05	1215	16.8	02/06	1600	16.3	(-0.5)
14/06	1030	16.0	16/06	1145	17.2	+1.2
28/06	1000	15.5	29/06	1050	17.5	+2.0
13/07	1000	18.0	14/07	1040	19.5	+1.5
03/08	1000	22.7	04/08	1125	23.4	+0.7
23/08	1010	17.0	24/08	1130	19.5	+2.5
20/09	1030	6.5	21/09	1145	8.0	+1.5
12/10	1045	7.5	---	---	--	---
15/11	1130	1.0	16/11	1015	0.5	(-0.5)
1984						
01/02	0930	0.5	02/02	1315	0.3	(-0.2)

mean ΔT= 0.9°C

---

* these Devon and Pakan data not comparable because of the long delay in sampling at Pakan for this sampling event.

TABLE 6.2 Temperature summary (°C) for the North Saskatchewan River, Beverly Bridge (centre-channel site) and Clover Bar (right-bank site) locations, 1982.

Date	Beverly Bridge	Clover Bar	difference
18/05	14.0	16.0	2.0
01/06	15.5	18.1	2.6
15/06	19.5	21.5	2.0
29/06	16.0	16.5	0.5
13/07	18.0	19.0	1.0
27/07	19.0	20.0	1.0
10/08	20.5	21.5	1.0
24/08	19.0	20.5	1.5
08/09	16.0	18.5	2.5
05/10	8.1	9.4	1.3
19/10	5.0	6.5	1.5
02/11	1.0	2.0	1.0
		mean difference =	1.5°C

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represent ambient temperature conditions. These two sites were sampled at nearly the same time of day; therefore, the influence of diurnal temperature variation is minimal. In 1982, the mean Clover Bar right-bank temperature was 1.5°C higher than the mean Beverly Bridge centre-channel temperature. The largest temperature difference measured between the sites was 2.6°C.

6.2 Surface Water Quality Objectives

The Alberta Surface Water Quality Objectives (Alberta Environment 1977) state that the temperature of surface waters is "not to be increased by more than 3°C above ambient water temperature" due to the addition of heated effluents from thermal plants or other industrial or municipal sources. At no time in the course of this study was this objective exceeded at any study location in the study section of the NSR.

6.3 Impacts

Beginning in 1972 and ending in 1975, a study was commissioned by Edmonton Power to determine the effects of the heated condenser water discharges from the Clover Bar generating station on the NSR. It was concluded that the thermal plume had little impact on the biological communities: "Although fish were attracted in large numbers to the thermal plume, minimal changes were observed in bacterial or invertebrate populations or in dissolved oxygen concentrations, pH, conductivity, or trace metal content of river sediments [sic]" (Edmonton Power 1975).

A possible beneficial impact of heated effluents is discussed at more length in the dissolved oxygen section of this report (Section 7.3). In short, the open water created by heated effluents in winter may enhance the reoxygenation process by exposing the water to the air.

Many physical, chemical, and biological processes in the aquatic environment are temperature sensitive. The solubility of oxygen decreases with increasing temperature, whereas the oxygen requirements of living organisms for respiration and metabolism increase as temperatures rise. Temperature affects the solubility of many elements and compounds and may affect the degree of influence certain pollutants have on aquatic life. Temperature affects growth rates, breeding, and propagation of aquatic organisms, some of which are more tolerant to unnatural variations or fluctuations than others.

7.0 DISSOLVED OXYGEN

Oxygen is one of the atmospheric gases which occurs in dissolved form in natural surface waters. It is moderately soluble in water, but saturation concentration depends upon temperature, atmospheric pressure, turbulence and salinity. For instance, the solubility of oxygen at 0°C in a given water body is approximately twice that at 35°C, where all other conditions remain constant. Actual concentrations are influenced mainly by biodepletion, by photosynthetic activity, and by re-oxygenation from the atmosphere. The bacterial decomposition of organic materials and the chemical oxidation of both organic and inorganic wastes may greatly reduce or deplete dissolved oxygen in surface waters. Inadequate dissolved oxygen concentrations may contribute to unfavorable environmental conditions for many aquatic organisms, and may be conducive to taste and odor problems resulting from anaerobic decomposition.

Dissolved oxygen was measured at the same sites and on the same dates as major chemical variables (Tables 4.4 and 4.5) with the exception that the Devon and E.L. Smith locations included discrete measurements for temperature at left-bank, centre-channel and right-bank sites. Details of methods are given in general methods (Section 5.0).

7.1 Results and Discussion: Dissolved Oxygen

The median dissolved oxygen concentrations for all left-bank and right-bank sites throughout this study are plotted in Figure 7.1; median temperatures for the same dates and sites are also shown.

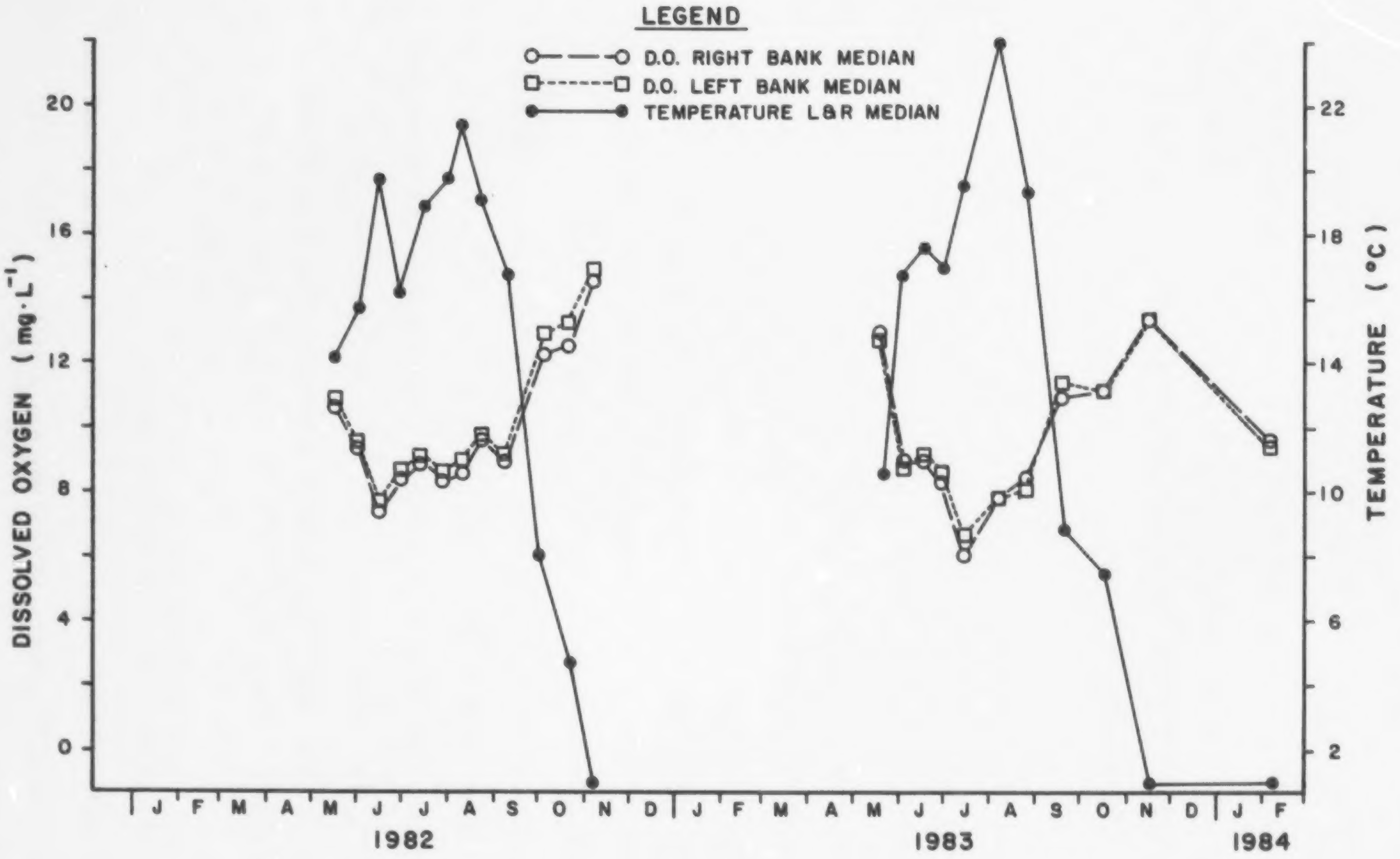

Fig. 7.1 Median dissolved oxygen and water temperature, North Saskatchewan River, 1983-1984.

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During May 1982, dissolved oxygen concentrations in the study section of the NSR ranged from 9.5 to 11.3 $mg \cdot L^{-1}$, representing 101 to 111% saturation. By mid-June 1982, all sites had seasonal lows, ranging from 6.6 to 8.5 $mg \cdot L^{-1}$ (80 to 95% saturation). From July onward in 1982, there was a trend towards higher dissolved oxygen concentrations, reaching 12.4 to 15.0 $mg \cdot L^{-1}$ (95 to 114% saturation) in November. The seasonal dissolved oxygen pattern was similar in 1983, except that seasonal lows from 5.3 to 7.2 $mg \cdot L^{-1}$ (63 to 85% saturation) in July were slightly lower than 1982 lows. Dissolved oxygen values in mid-winter (February 1984) had declined, ranging from 8.5 to 11.8 $mg \cdot L^{-1}$ (65 to 89% saturation).

A spatial overview of dissolved oxygen, expressed as percent saturation, in the study section of the NSR is given in Table 7.1.

Median dissolved oxygen values for left-bank and right-bank sites for each of the six locations sampled in both 1982 and 1983 ranged from 98% to 108% saturation. The values for all left-bank and right-bank sites were compared statistically to the corresponding upstream values at Devon. Except for the Vinca left-bank site (median = 108%), no sites were significantly different from Devon ($P<0.05$, $n = 20$).

Variations in dissolved oxygen observed on the NSR are more the result of seasonal than spatial influences. The inverse seasonal pattern of dissolved oxygen and temperature (Fig. 7.1) is characteristic of all sites. Water temperature is a primary

TABLE 7.1 Dissolved oxygen as percent saturation for selected sites on the NSR from May 1982 to February 1984

location	left bank median (range)	right bank median (range)
Devon Bridge	100 (74 - 126)	100 (75 - 125)
50th Street Footbridge	102 (65 - 125)	98 (66 - 124)
Beverly Bridge	101 (71 - 124)	100 (66 - 127)
Fort Saskatchewan	105 (71 - 129)	107 (71 - 136)
Vinca	108 (67 - 151)	98 (62 - 125)
Pakan	102 (67 - 135)	98 (65 - 135)

determinant of oxygen solubility and, therefore, an important factor governing dissolved oxygen concentrations in the river. Although concentrations vary seasonally from about 6 to 14 $mg \cdot L^{-1}$, this range usually represents saturation or near saturation. However, there were two exceptions to this general condition during the study period:

1) On February 28 - 29, 1984, a concentration of 9.5 $mg \cdot L^{-1}$ (median for all sites) represented approximately 71% saturation. A winter depression in dissolved oxygen levels in rivers and streams is a normal condition, partly because icecover prevents re-aeration, and partly because photosynthetic activity is greatly reduced at this time of year.
2) On July 13 - 14, 1983, dissolved oxygen averaged 72% saturation (Fig. 7.2). Causes of the low dissolved oxygen conditions observed are uncertain. Dissolved oxygen concentrations from the Vinca continuous monitor site (Robot Monitor Program, Alberta Environment) for July 13 - 14, 1983, ranged from 7.1 to 7.6 $mg \cdot L^{-1}$, representing approximately 85 to 90% saturation; this study data from Vinca on the same date gave values of 5.6 $mg \cdot L^{-1}$ (66% saturation). Local spatial variations or meter calibration problems were possible.

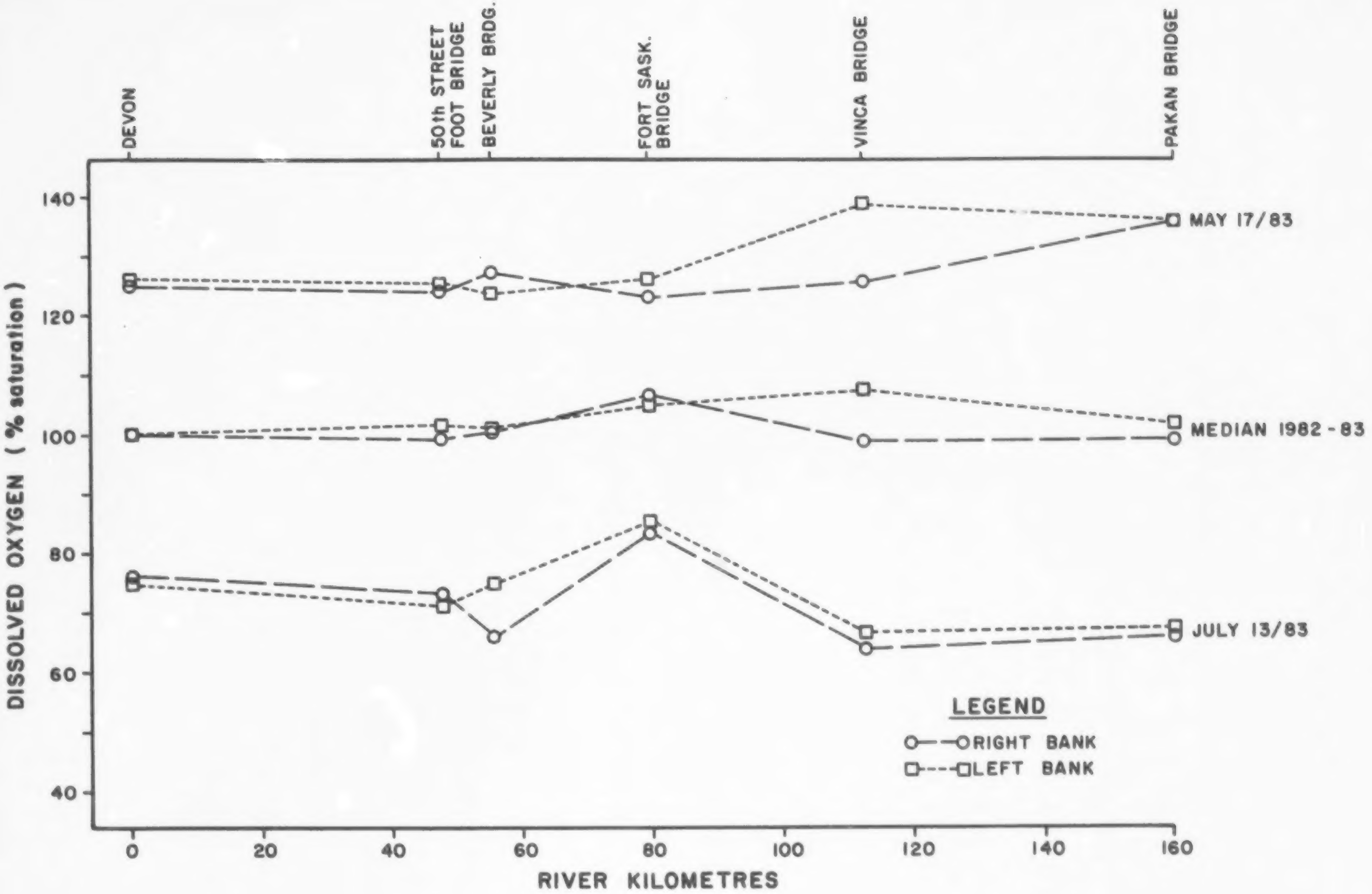

Fig. 7.2 Dissolved oxygen as percent saturation, North Saskatchewan River, 1982-1984. Median values for study period and values for selected dates are given for six sampling locations.

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7.2 Surface Water Quality Objectives

The Alberta Surface Water Quality Objectives (Alberta Environment 1977) recommend a minimum dissolved oxygen concentration of 5 $mg{\cdot}L^{-1}$ at any time. A concentration of 5 $mg{\cdot}L^{-1}$ or more is necessary to protect fisheries and plant life, to guard against the onset of septic conditions, and to enable a waterbody to assimilate organic material adequately.

Throughout this investigation, measured dissolved oxygen values were above the 5 $mg{\cdot}L^{-1}$ objective. The lowest readings occurred on July 13 - 14, 1983, when values ranged from 5.3 to 5.8 $mg{\cdot}L^{-1}$ at both Vinca and Pakan.

Dissolved oxygen requirements and criteria specific to freshwater life have been developed by the National Research Council of Canada (Davis 1975). These criteria define three levels of harm (or risk) to various groupings of aquatic organisms based on percent saturation of dissolved oxygen over a range of water temperatures (Table 7.2). For the aquatic forms most typical of the NSR study section (freshwater mixed fish population with no salmonids), dissolved oxygen saturation above 60% provides a high degree of protection. This objective was achieved throughout the duration of the present study.

7.3 Impacts

As long as dissolved oxygen in the NSR is maintained at or above the levels found in this study (i.e. above 5 $mg{\cdot}L^{-1}$, or

TABLE 7.2 Oxygen Criteria[a] for Assessment of Harm in Various Freshwater and Marine Fish Groups (from Davis 1975).

Group	Harm Commitment Level	Percentage saturation at each temperature (°C)					
		0	5	10	15	20	25
Freshwater mixed fish population, including some salmonids	A	69	70	70	71	79	87
	B	54	54	54	54	57	63
	C	38	38	38	38	39	39
Freshwater mixed fish population with no salmonids	A	60	60	60	60	60	66
	B	47	47	47	47	47	48
	C	35	35	35	35	35	36
Primarily freshwater salmonid population (including steelhead)	A	76	76	76	76	85	93
	B	57	57	57	59	65	72
	C	38	38	38	42	46	51
Salmonid larvae and mature eggs of salmonids	A	98	98	98	98	100	100
	B	76	76	76	79	87	95
	C	54	54	57	64	71	78
Marine, non-anadromous species	A	88	88	95	100	100	100
	B	69	69	74	82	90	98
	C	50	51	51	55	60	65
Anadromous marine species, including salmonids	A	100	100	100	100	100	100
	B	79	79	79	79	87	94
	C	57	57	57	57	57	58

[a] These criteria are defined as oxygen minima in percentage saturation allowable at seasonal temperature maxima. Three levels of harm commitment are given (A, B and C), to allow for flexibility of application. Level A provides the highest degree of protection, level C provides the lowest.

>60% saturation, whichever is higher), few or no adverse effects can be expected from less-than-saturation dissolved oxygen levels. However, two critical periods warrant continued vigilance: the winter period and the mid-summer period.

Typically, winter oxygen levels in river waters drop because of oxygen consumption in the water and underlying sediments, combined with low levels of photosynthetic activity by plants, lower flow levels, and reduced reoxygenation from the air during the period of icecover. Winter oxygen reduction can be aggravated due to the presence of large amounts of organic matter, which can either be produced in the river itself or added via effluents entering the river. The lessening of winter oxygen depletion problems in the NSR since 1960 has been due primarily to the implementation of two measures: the enhancement of winter flows through discharge control at the Bighorn and Brazeau dams (Fig. 1.1), and the reduction in oxygen-consuming organic matter being discharged into the river in wastewater treatment plant effluents (Bouthillier 1983). By causing an extensive section of the NSR to remain open in winter, thus permitting enhanced reoxygenation to occur, a moderate amount of thermal pollution is probably also contributing to better winter oxygen conditions.

Nocturnal oxygen depletion is sometimes a problem in rivers during midsummer due to a combination of reduced photosynthetic activity during hours of darkness or low light and an increase in respiration at this time because of a greater living biomass (especially algal) which metabolizes at higher rates at warmer temperatures. Dissolved oxygen analyses were performed only during daylight hours throughout this study and, although there was no direct evidence of problems due to midsummer nocturnal oxygen depletion in 1982 or 1983, it is likely that nighttime oxygen levels were somewhat lower than daytime levels. As in the case of winter oxygen reduction, any enhanced algal growth in the future could increase the potential for midsummer nocturnal oxygen depletion.

8.0 MAJOR IONS AND RELATED VARIABLES

An analysis of longitudinal and lateral trends in the major ions and related variables for the Devon to Pakan section of the North Saskatchewan River (NSR) was made to characterize the general conditions in the river as they existed during the 1982 and 1983 field seasons (including 2 winter dates, 1984).

Two levels of analysis were undertaken: an overview analysis of trends at Devon and Pakan to identify consistent temporal and spatial changes in river chemistry, and a detailed analysis in which these changes were related to known point sources of materials (i.e. industries, municipalities, tributary streams, etc).

8.1 Results and Discussion

The median concentrations throughout the study period for the Devon location (composite sample) and the Pakan location (separate left-bank, centre-channel, and right-bank samples) are presented in Table 8.1. The study section of the NSR is alkaline freshwater (total salinity < 1000 $\mathrm{mg \cdot L^{-1}}$; McNeely *et al*. 1979) in which calcium-bicarbonate predominates. Although the river transects the parkland biome where the northern edge of the saline lake zone occurs (Northcote and Larkin 1966), the salinity of the river water in this region increases very little, because the contribution of water and dissolved salts from these saline basins is small relative to the flow of the NSR in the central and eastern portions of Alberta. Water

TABLE 8.1 Median Concentrations of Major Ions and Related Variables in the North Saskatchewan River for the study period 1982-1983 (n = number of observations).

	Devon		Pakan LB	Pakan C	Pakan RB	
Calcium (mg•L^{-1})	41	(n=24)	42	41	42	(n=23)
Magnesium (mg•L^{-1})	11.0	(n=24)	12.0	11.0	11.0	(n=12)
Sodium (mg•L^{-1})	4.0	(n=24)	8.0	7.0	7.0	(n=23)
Potassium (mg•L^{-1})	0.8	(n=24)	1.2	1.2	1.1	(n=23)
Bicarbonate (mg•L^{-1})	154	(n=22)	162	161	163	(n=21)
Chloride (mg•L^{-1})	1.0	(n=24)	3.0	2.0	2.0	(n=23)
Sulphate (mg•L^{-1})	35.0	(n=24)	40	40	40	(n=23)
Total Alk. (mg•L^{-1})	132	(n=24)	134	133	134	(n=23)
pH	8.4	(n=24)	8.0	8.2	8.1	(n=23)
TDS (mg•L^{-1})	172	(n=24)	187	182	188	(n=23)
NFR (mg•L^{-1})	11	(n=17)	12	16	13	(n=16)
Conductance (uS•cm^{-1})	317	(n=24)	352	343	349	(n=23)
Silica (mg•L^{-1})	3.9	(n=24)	3.0	3.2	3.2	(n=23)
Fluoride (mg•L^{-1})	0.13	(n=24)	0.15	0.15	0.15	(n=23)

LB = Left Bank
C = Centre
RB = Right Bank

supply and demand studies for the NSR basin have indicated that approximately 95% of the flow measured at the Saskatchewan border is derived upstream of Drayton Valley (D. Barton, Planning Division, pers. comm.).

Variations in major ion concentrations over time were similar for most variables at both the Devon and Pakan locations, although several constituents at Pakan exhibited peaks in mid May which were absent at the upstream location. In general, the maximum annual ionic concentrations, total dissolved solids (TDS), and specific conductances were observed during the summer low flow period (August), with high concentrations also observed during winter low flows. The lowest values were observed during the period of maximum annual discharge in late June and early July. The range of concentration and specific conductance changes was small compared to variations in discharge and no significant statistical correlations could be determined.

The non-filterable residue (NFR) measurement represents the solid material (approximately 1 μm or larger) that is suspended in river water and that can be removed by 0.4 μm polycarbonate membrane filtration and measured. Unlike concentrations of dissolved components, NFR concentrations and variations are frequently discharge dependent (Whitton 1975). At both Devon and Pakan, a distinct seasonality in NFR concentrations was observed. Peak concentrations occurred during the period of mountain snowmelt in late June and early July. The lowest concentrations were observed during the late summer and winter low-flow periods.

During this study, there was no change in the pattern of ionic dominance between the Devon and Pakan sampling locations; the cation sequence was $Ca^{++} > Mg^{++} > Na^{+} > K^{+}$, and the anion sequence was $HCO_3^{-} > SO_4^{=} > Cl^{-}$. This pattern is encountered frequently in the freshwater lakes of the parkland and boreal mixed wood forest biomes of central Alberta (Trew et al. 1981; Trew et al. 1985; Water Quality Control Branch 1984, 1985a, 1985b), and is the prevalent pattern of ionic dominance in North American freshwaters (Whitton 1975).

Although there was no change in the patterns of ionic dominance between Devon and Pakan, it is reasonable to expect a progressive downstream increase in the concentration of dissolved substances as a result of the natural weathering of organic and inorganic materials in the watershed, the transport of these dissolved substances via runoff into the tributaries and mainstem river (Whitton 1975), and the further concentration of these substances as a consequence of evaporation. Such increases are apparent for most of the constituents listed in Table 8.1, but the relative changes are less than 10% in most cases. The notable exceptions are the concentrations of sodium, potassium and chloride ions.

In order to determine the significance of pattern changes for these three ions, the differences were tested statistically using the Wilcoxon signed-rank matched-pairs test (see Section 5.3). In order to pair upstream and downstream data for testing, the Pakan data had to be reduced from three values per sampling trip to a single value.

Assuming that the river is well mixed at Pakan, a single value for each variable for each date was calculated for the Pakan site by calculating the mean of left-bank, centre-channel, and right-bank results. This mean value was then paired with the corresponding composite sample value from Devon and tested statistically. The upstream and downstream values during 1982-1983 were significantly different for all three variables ($P < 0.05$, $n = 21$).

In order to identify the potential sources of materials contributing to the spatial patterns, a detailed analysis of longitudinal changes in river concentrations was performed. The 1983 median values for sodium, potassium, and chloride at each location and site were tabulated along with estimated daily loadings (1983) for the industrial and municipal point sources listed in Tables 4.1 and 4.2. A further analysis of river chemistry changes and associated point source loadings was performed for a single sampling trip in 1983 (August 3-4) for which simultaneous industrial, municipal, major tributary and river data were available.

The daily loadings for each industrial or municipal point source were estimated from the product of median concentration and median discharge for each effluent determined during the 1983 sampling program. Although daily loadings are best estimated from the analysis of daily data, these data were not available for the point sources in question. However, the day-to-day variations in industrial or municipal point source loadings are small compared to natural stream loadings. The data are summarized in Tables 8.2 and 8.3.

TABLE 8.2 Estimated Industrial Daily Loadings ($kg \cdot d^{-1}$) to North Saskatchewan River.

Code	Industry	Chloride	Sodium	Potassium
I 5	Stelco	119.8	30.8	127.8
I 6	C.I.L.	3.1	0.7	3.6
I 7	Imperial Oil Refinery	1,688.4	923.0	40.0
I 9	Texaco	459.0	271.8	9.7
I 10	Gulf Refinery	349.5	236.7	5.9
I 11	Celanese South Flume	316.5	385.5	29.5
	Celanese North Flume	4.1	4.7	1.1
I 14	Alberta Food Products	8.3	12.0	1.9
I 16	Sherritt Gordon			
	Final Effluent	73.5	175.9	12.0
	South West Pond	45.3	255.2	11.7
I 17	Union Carbide	9.0	3.6	0.7
I 18	Dow Chemical	2,835.4	2,172.6	28.7
I 20	Diamond Shamrock	202.1	135.4	2.2
I 22	Esso Chemical, Redwater	44.9	314.1	27.9
	TOTAL	6,158.9	4,922.0	302.7

TABLE 8.3 Estimated Municipal Daily Loadings ($kg \cdot d^{-1}$) to North Saskatchewan River.

Code	Municipality	Chloride	Sodium	Potassium
M 3	Devon STP	65.5	103.9	14.9
M 9	GBWTP, Edmonton	12,382.0	18,937.1	2,452.1
M 10	Bremner Lagoons	1,707.6	2,323.5	476.0
M 11	St. Albert	441.6	790.2	122.0
M 13	Fort Saskatchewan	146.2	217.6	38.3
	TOTAL	14,742.9	22,372.3	3,103.3

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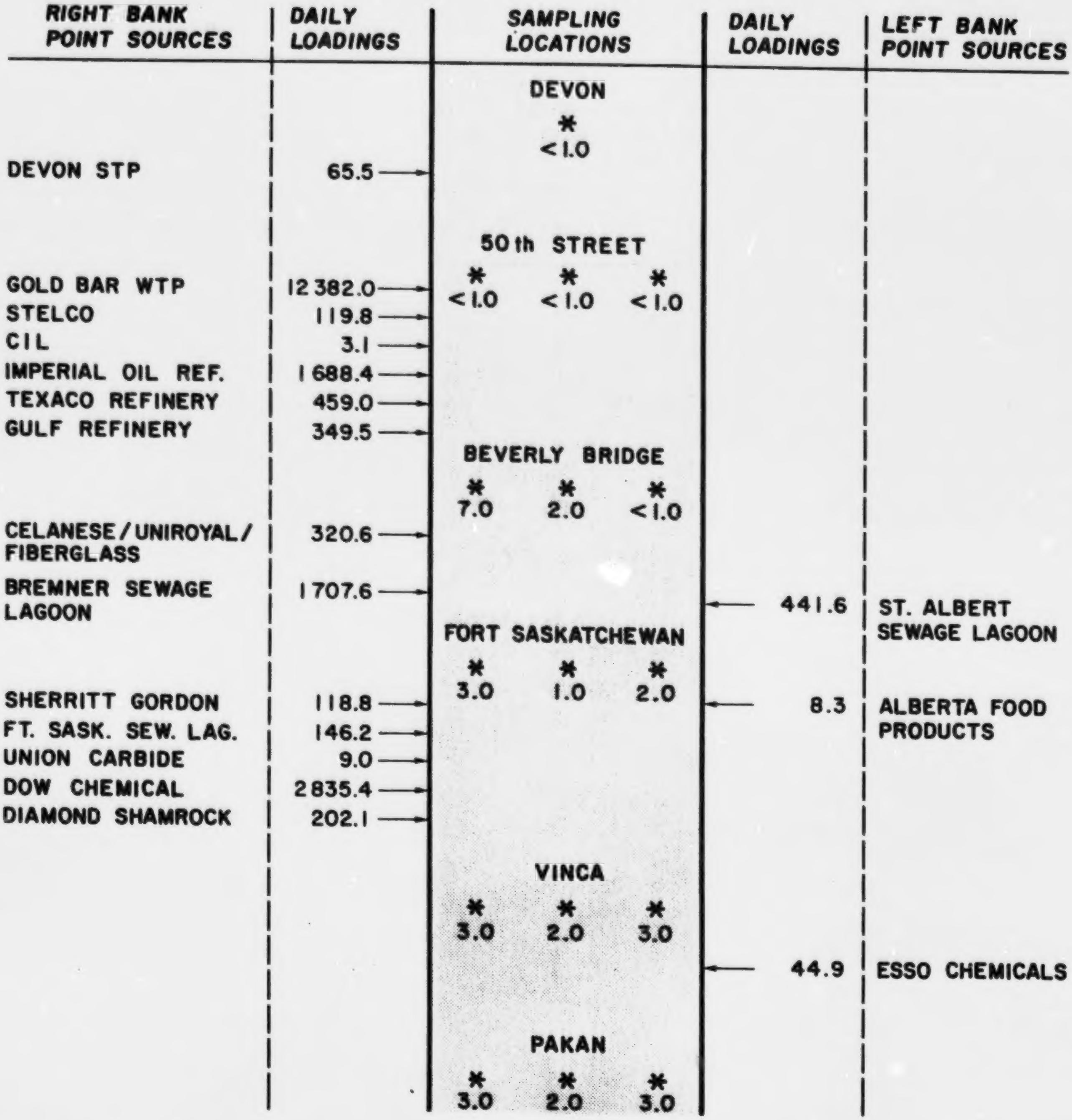
Some samples were also collected during 1983 from the four major tributary streams to the study section (Whitemud Creek, Beaverhill Creek, Sturgeon River, Redwater River). The use of median concentration and flow data would be inappropriate for estimating daily loads in these streams because the seasonal nature of stream discharge gives highly variable values. An ideal technique for estimating daily loadings is to apply an established material flux versus discharge model for the tributary in question (Yaksich et al. 1983), but the infrequent chemical sampling of these streams precluded the use of such a regression model, even though daily discharge data were available from the Water Survey of Canada gauges on each stream. Therefore, the daily loadings for each ion from each stream have been calculated from the measurements of concentrations and discharges on specified dates in 1983; they are summarized in Table 8.4 but are not reduced to a single daily loading value for comparison with the estimated daily industrial and municipal loads. Loading data are unavailable for several smaller creeks and for all storm sewers.

8.1.1 Chloride

The median chloride concentrations were less than the detection level of 1.0 $mg \cdot L^{-1}$ at all locations upstream of the Beverly Bridge (Figure 8.1). The daily loadings from the Devon sewage treatment plant were apparently too small to affect river chloride concentrations in this region. At the Beverly Bridge location, a

TABLE 8.4 Estimated daily loading of sodium, chloride and potassium via tributary streams to the North Saskatchewan River (kg•d⁻¹)

	chloride	sodium	potassium
Whitemud Creek			
17/05/83	22.5	65.7	9.5
31/05/83	172.8	673.9	121.0
28/06/83	10782.7	32348.2	10513.2
13/07/83	7318.1	33454.1	12545.3
03/08/83	1010.9	4268.2	1460.2
23/08/83	21.6	95.0	13.8
20/09/83	27.6	112.3	8.6
12/10/83	63.1	241.9	20.7
Redwater River			
26/05/83	483.8	388.8	55.3
02/06/83	1002.2	812.2	112.3
16/06/83	449.3	518.4	69.1
29/06/83	9322.6	21513.6	4155.8
14/07/83	1969.9	6894.7	2168.6
04/08/83	829.4	1866.2	388.8
24/08/83	146.9	181.4	24.2
21/09/83	596.2	440.6	36.3
Beaverhill Creek			
29/06/83	3525.1	30551.0	6696.0
14/07/83	829.4	8017.9	1987.2
04/08/83	216.0	1382.4	354.2
24/08/83	9.5	34.6	8.6
21/09/83	3.1	6.7	1.0
Sturgeon River			
26/05/83	1036.8	7465.0	1702.1
02/06/83	967.7	5253.1	1149.1
16/06/83	760.3	3732.5	509.8
29/06/83	7439.0	36132.5	6480.0
14/07/83	3767.0	29194.6	7249.0
04/08/83	2592.0	15984.0	3542.4
24/08/83	881.3	6169.0	1192.3
21/09/83	388.3	2116.8	345.6



RIGHT BANK POINT SOURCES	DAILY LOADINGS	SAMPLING LOCATIONS	DAILY LOADINGS	LEFT BANK POINT SOURCES
		DEVON		
		* <1.0		
DEVON STP	65.5 →			
		50th STREET		
GOLD BAR WTP	12 382.0 →	* <1.0 * <1.0 * <1.0		
STELCO	119.8 →			
CIL	3.1 →			
IMPERIAL OIL REF.	1 688.4 →			
TEXACO REFINERY	459.0 →			
GULF REFINERY	349.5 →			
		BEVERLY BRIDGE		
		* 7.0 * 2.0 * <1.0		
CELANESE / UNIROYAL / FIBERGLASS	320.6 →			
BREMNER SEWAGE LAGOON	1 707.6 →		← 441.6	ST. ALBERT SEWAGE LAGOON
		FORT SASKATCHEWAN		
		* 3.0 * 1.0 * 2.0		
SHERRITT GORDON	118.8 →		← 8.3	ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.	146.2 →			
UNION CARBIDE	9.0 →			
DOW CHEMICAL	2 835.4 →			
DIAMOND SHAMROCK	202.1 →			
		VINCA		
		* 3.0 * 2.0 * 3.0		
			← 44.9	ESSO CHEMICALS
		PAKAN		
		* 3.0 * 2.0 * 3.0		

TOTAL INDUSTRIAL LOAD = 6 158.9
TOTAL MUNICIPAL LOAD = 14 742.9
TOTAL DAILY LOAD = 20 901.8

Fig. 8.1 Diagrammatic representation of 1983-84 median chloride concentrations ($mg \cdot L^{-1}$) and estimated municipal and industrial point source loadings ($kg \cdot d^{-1}$).

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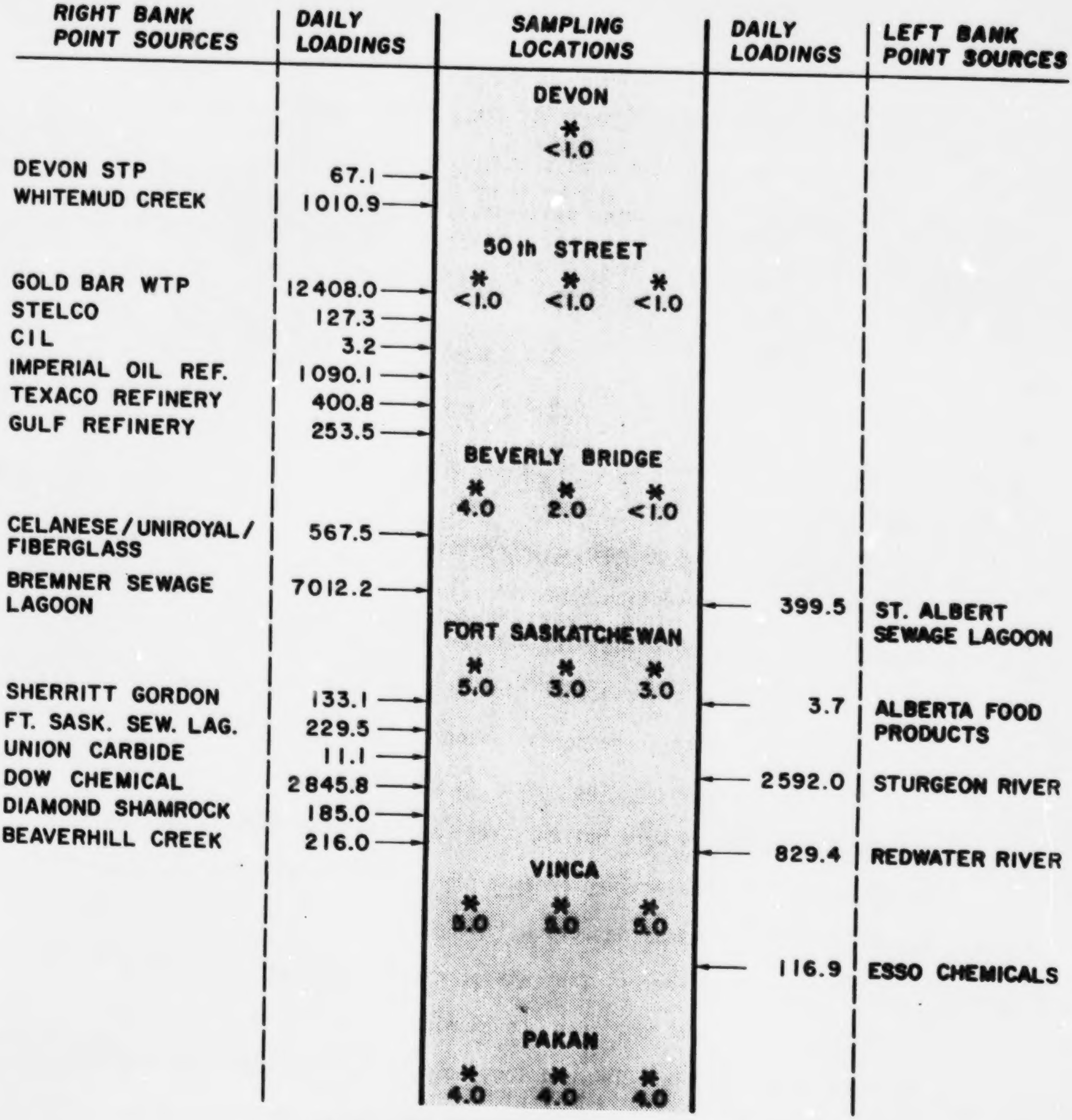
relatively high median concentration of 7.0 $mg \cdot L^{-1}$ characterized the right-bank site, whereas the left-bank median remained less than the detection level. This concentration change was clearly associated with the seven point sources illustrated in Figure 8.1.

The median concentrations at Fort Saskatchewan Bridge, Vinca Bridge and Pakan Bridge revealed similar spatial characteristics with the centre-channel site always having the lowest concentrations. Median chloride concentrations at left-bank and centre-channel sites were above the detection limit at the Fort Saskatchewan Bridge location, but it is not possible to ascertain whether this is due to lateral mixing of the right-bank chloride loadings, or a combination of mixing and left-bank loading from the St. Albert sewage treatment plant outfall. A detailed study of the mixing regime of the NSR in the vicinity of these effluents would be required in order to resolve this issue.

A wide range of continuous point source loadings of chloride was suggested by the loading analysis. The daily loads range from 8.3 $kg \cdot d^{-1}$ to 12382.0 $kg \cdot d^{-1}$; the latter source was the City of Edmonton's Gold Bar Wastewater Treatment Plant (GBWTP) which contributed over half the continuous daily load of 20,901.8 $kg \cdot d^{-1}$ as estimated by this technique. As a group, the municipal discharges contributed approximately 70.5% of the combined industrial and municipal loads; most of the point-source chloride loading enters the river on the right bank between GBWTP and the mouth of the Sturgeon River.

Because chloride is usually considered a conservative constituent (Wetzel 1975), a simple dilution analysis can be used to compare daily point source loading estimates with the difference between daily river loads upstream and downstream of the City of Edmonton. The results from sampling trips closest to dates when discharges approximated mean annual discharges for each of the 1982 and 1983 study years were used in the comparisons. For October 5-6, 1982, the daily river chloride loads at Devon and Pakan were estimated to be 18403 and 36806 $kg \cdot d^{-1}$, respectively - a downstream increase of 18403 $kg \cdot d^{-1}$. For August 23-24, 1983, the daily loads at Devon and Pakan were estimated at 13910 and 27820 $kg \cdot d^{-1}$, respectively - a downstream increase of 13910 $kg \cdot d^{-1}$. Because the concentrations at Devon on both trips were below the detection limit and were assumed to be 1.0 $mg \cdot L^{-1}$ for calculation purposes, these loadings may be slightly underestimated. However, they tally well with the point-source estimates, especially in consideration of the small data base and the technique employed in the calculation of point-source loads.

The river chloride concentrations and detailed point-source loadings measured during August 3-4, 1983 are illustrated in Figure 8.2. The general pattern of concentration changes was similar to that portrayed by the median concentration data. Concentrations were below detection at the Devon and 50th Street Footbridge locations, but rose sharply at the Beverly Bridge right-bank site. At the Fort Saskatchewan Bridge, all samples were above detection, but again right-


RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
* <1.0
DEVON STP 67.1
WHITEMUD CREEK 1010.9
50th STREET
* <1.0 * <1.0 * <1.0
GOLD BAR WTP 12408.0
STELCO 127.3
CIL 3.2
IMPERIAL OIL REF. 1090.1
TEXACO REFINERY 400.8
GULF REFINERY 253.5
BEVERLY BRIDGE
* 4.0 * 2.0 * <1.0
CELANESE/UNIROYAL/FIBERGLASS 567.5
BREMNER SEWAGE LAGOON 7012.2
399.5 ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
* 5.0 * 3.0 * 3.0
SHERRITT GORDON 133.1
FT. SASK. SEW. LAG. 229.5
UNION CARBIDE 11.1
DOW CHEMICAL 2845.8
DIAMOND SHAMROCK 185.0
BEAVERHILL CREEK 216.0
3.7 ALBERTA FOOD PRODUCTS
2592.0 STURGEON RIVER
829.4 REDWATER RIVER
VINCA
* 5.0 * 5.0 * 5.0
116.9 ESSO CHEMICALS
PAKAN
* 4.0 * 4.0 * 4.0

TOTAL TRIBUTARY LOAD	=	4 648.3
TOTAL INDUSTRIAL LOAD	=	5 738.0
TOTAL MUNICIPAL LOAD	=	20 116.3
TOTAL DAILY LOAD	=	30 502.6

Fig. 8.2 **Diagrammatic representation of Aug. 3-4/83 chloride concentrations (mg · L^{-1}) and estimated municipal, tributary and industrial point source loadings (kg · d^{-1}) .**

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bank concentrations were higher. At Vinca Bridge and Pakan bridge concentrations were uniform across the river.

The breakdown in measured daily loadings during August 3-4, 1983, was as follows:

Industrial	5,834.4 $kg{\cdot}d^{-1}$
Municipal	20,020.0 $kg{\cdot}d^{-1}$
Tributaries	4,648.3 $kg{\cdot}d^{-1}$
Total	30,502.7 $kg{\cdot}d^{-1}$

Once again, the municipal discharges were the largest source of chloride loads, representing approximately 65.6% of the total input. The total change in chloride mass between Devon and Pakan was also determined from flow and concentration data to be approximately 37,324.8 $kg{\cdot}d^{-1}$, which corresponds reasonably well with the total measured inputs. However, the reader is cautioned that storm sewers and small tributaries were not measured, and that the precise mass at Devon could not be determined because the river chloride concentration was below the analytical detection limit.

The great influence of the rate of river discharge on chloride concentrations is apparent upon the examination of the more detailed chloride data from high-flow and low-flow periods in 1982. The mean daily discharge for the North Saskatchewan River at Edmonton during 1982 was 218 $m^3{\cdot}s^{-1}$ (Water Survey of Canada, Station 05DF001). Thus, the discharge rate at this station during sampling trips on July 27, 1982 ($Q = 393$ $m^3{\cdot}s^{-1}$) and August 24, 1982 ($Q = 118$ $m^3{\cdot}s^{-1}$) are representative of relatively high and low flows.

On July 27, 1982, chloride concentrations of 2.0 mg•L^{-1} in right-bank samples from the Beverly Bridge and Pakan locations, and both right-bank and left-bank samples from Vinca were the only ones observed above the analytical detection limit (Table 8.5). All other sites upstream and downstream of Edmonton yielded chloride concentrations less than 1.0 mg•L^{-1}. This pattern is quite different from that for 1983 median chloride concentrations (Figure 8.1) and implies that dilution, turbulence and mixing were sufficient to mask the continuous point-source inputs of chloride.

In contrast, the 1982 data for August 24 during low flow showed a longitudinal pattern (Table 8.6) similar to that for 1983 median concentrations. Chloride concentrations were below the analytical detection limit upstream of the main point sources, but were generally as high as the 1983 median values at the Beverly Bridge right-bank site and downstream. At this time, mixing and dilution were insufficient to mask point-source chloride inputs. These few data indicate that mixing in the North Saskatchewan River is not constant in time or space and can be expected to vary greatly with the discharge rate.

8.1.2 Sodium

The longitudinal patterns for 1983 median sodium concentrations were similar to those for chloride (Figure 8.3). Upstream concentrations ranged from 4.0 to 6.0 mg•L^{-1}. The first major increase in median concentration was at the Beverly Bridge right-bank

TABLE 8.5 North Saskatchewan River Chloride Concentrations ($mg \cdot L^{-1}$) on July 27, 1982 (High Flow - 393 $m^3 \cdot s^{-1}$)

Sampling Locations	Right	Centre	Left
Devon		<1.0	
E.L. Smith		<1.0	
Rossdale	<1.0	<1.0	<1.0
50th Street Footbridge	<1.0	<1.0	<1.0
Rundle Bridge	<1.0	<1.0	<1.0
Beverly Bridge	2.0	<1.0	<1.0
Clover Bar	<1.0	<1.0	<1.0
Fort Saskatchewan Bridge	<1.0	<1.0	<1.0
Sturgeon River	<1.0	<1.0	<1.0
Vinca Bridge	2.0	<1.0	2.0
Pakan Bridge	2.0	<1.0	<1.0

< indicates value less than the analytical detection limit

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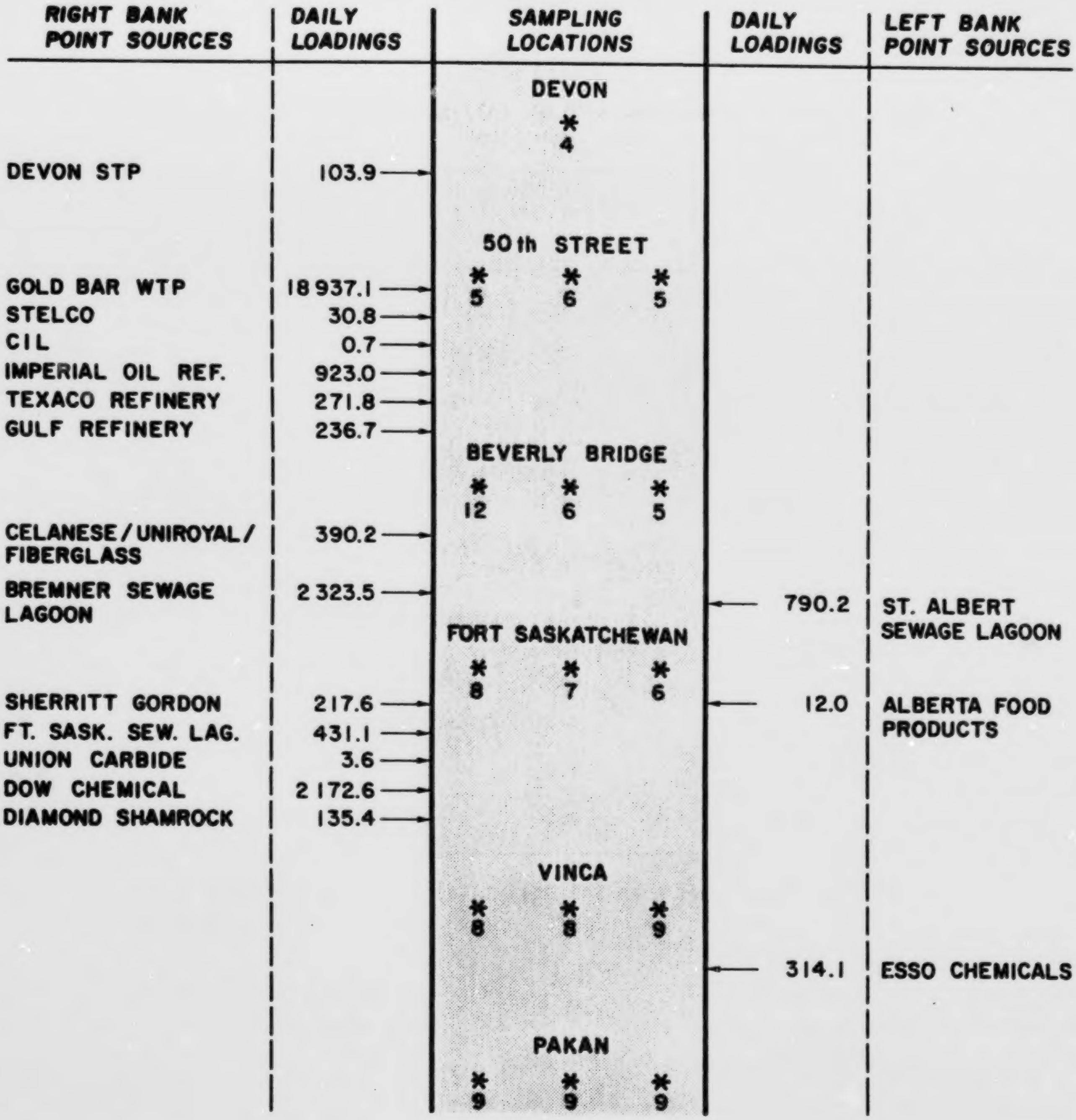
TABLE 8.6 North Saskatchewan River chloride concentrations ($mg \cdot L^{-1}$) on August 24, 1982 (low flow - 118 $m^3 \cdot s^{-1}$)

Sampling Locations	Right	Centre	Left
Devon		<1.0	
E.L. Smith		<1.0	
Rossdale	<1.0	<1.0	<1.0
50th Street Footbridge	<1.0	<1.0	<1.0
Rundle Bridge	<1.0	<1.0	<1.0
Beverly Bridge	4.0	<1.0	<1.0
Clover Bar	3.0	<1.0	<1.0
Fort Saskatchewan Bridge	4.0	2.0	2.0
Sturgeon River	8.0	3.0	3.0
Vinca Bridge	4.0	3.0	3.0
Pakan Bridge	2.0	3.0	3.0

< indicates value less than the analytical detection limit



RIGHT BANK POINT SOURCES	DAILY LOADINGS	SAMPLING LOCATIONS	DAILY LOADINGS	LEFT BANK POINT SOURCES
		DEVON * 4		
DEVON STP	103.9			
		50th STREET * * * 5 6 5		
GOLD BAR WTP	18 937.1			
STELCO	30.8			
CIL	0.7			
IMPERIAL OIL REF.	923.0			
TEXACO REFINERY	271.8			
GULF REFINERY	236.7			
		BEVERLY BRIDGE * * * 12 6 5		
CELANESE / UNIROYAL / FIBERGLASS	390.2			
BREMNER SEWAGE LAGOON	2 323.5			
			790.2	ST. ALBERT SEWAGE LAGOON
		FORT SASKATCHEWAN * * * 8 7 6		
SHERRITT GORDON	217.6		12.0	ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.	431.1			
UNION CARBIDE	3.6			
DOW CHEMICAL	2 172.6			
DIAMOND SHAMROCK	135.4			
		VINCA * * * 8 8 9		
			314.1	ESSO CHEMICALS
		PAKAN * * * 9 9 9		

TOTAL INDUSTRIAL LOAD = 4 922.0
TOTAL MUNICIPAL LOAD = 22 372.3
TOTAL DAILY LOAD = 27 294.3

Fig. 8.3 Diagrammatic representation of 1983-84 median sodium concentrations (mg·L^{-1}) and estimated municipal and industrial point source loadings (kg·d^{-1}) .

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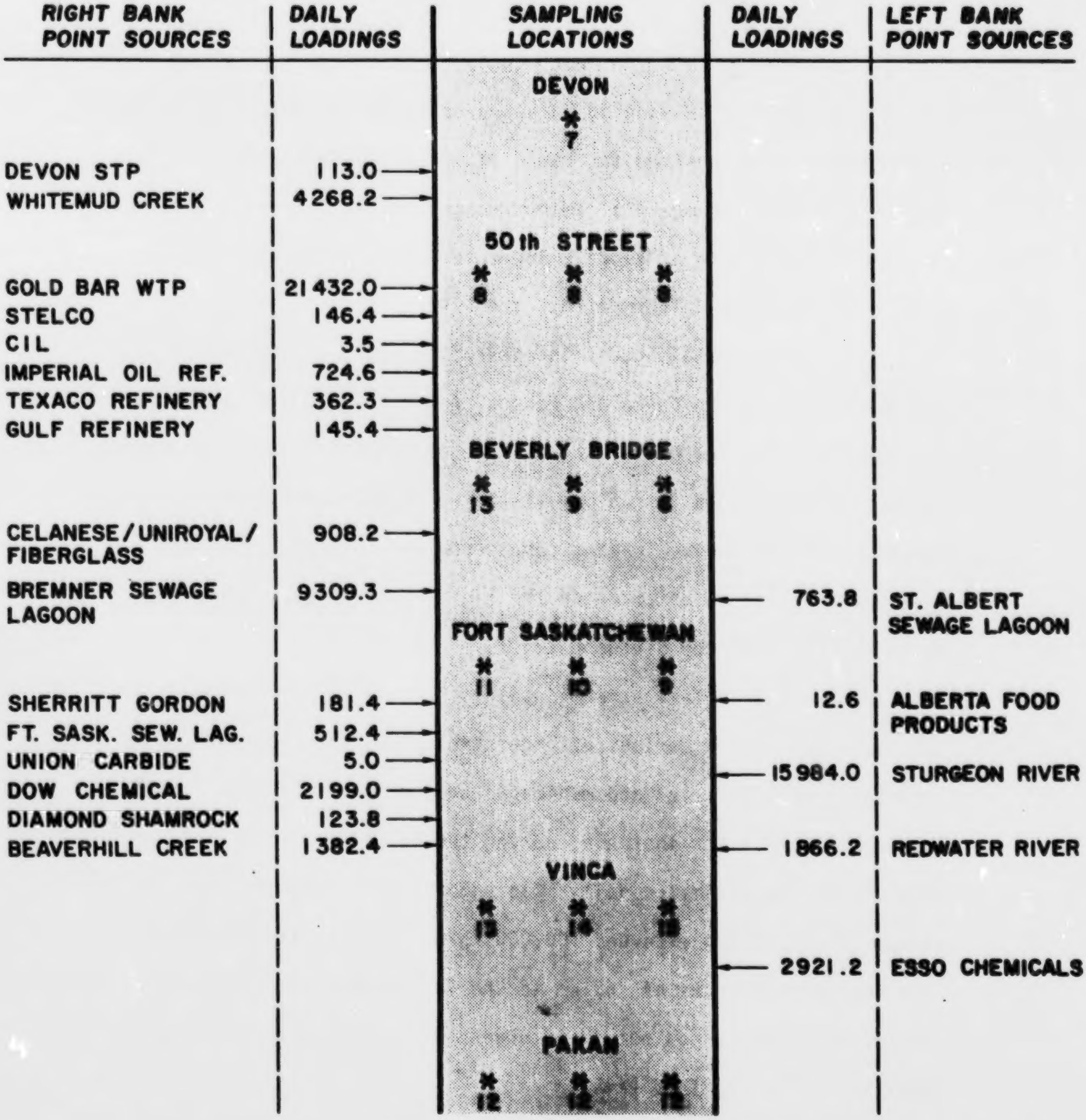
site (12.0 mg•L^{-1}). Mixing again appeared to be incomplete at Fort Saskatchewan, judging from the range of median concentrations at this location (6.0 to 8.0 mg•L^{-1}). Minor concentration increases occurred at the left-bank site at Vinca Bridge, but at Pakan Bridge concentrations were uniform across the river.

These median data suggest the nearly doubling of sodium concentration between Devon and Pakan. As in the case of chloride, the major portion (82.0%) of the average daily continuous point-source loading (27294.3 kg•d^{-1}) can be attributed to the GBWTP. Most of the remainder of the sodium loading comes from various industrial and municipal discharges entering on the right bank of the river between GBWTP and the mouth of Sturgeon River.

The daily tributary stream loadings calculated for sodium indicate that during periods of high streamflow, the relative importance of industrial and municipal sodium sources to the total load diminishes. For instance, during the sampling period of 28-29 June, 1983, the estimated daily loading of sodium from the four streams in Table 8.4 exceeded 100,000 kg•d^{-1}. Most streams became less important sources of sodium in the late summer and autumn as streamflows diminished, but the Sturgeon River remained a significant point source during this time.

The detailed sodium concentration and loading data for August 3-4, 1983, are presented in Figure 8.4. The data reveal a concentration increase of 5 mg•L^{-1} between Devon and Pakan, equivalent



RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
*
7
DEVON STP
113.0
WHITEMUD CREEK
4268.2
50th STREET
* 8
* 8
* 8
GOLD BAR WTP
21 432.0
STELCO
146.4
CIL
3.5
IMPERIAL OIL REF.
724.6
TEXACO REFINERY
362.3
GULF REFINERY
145.4
BEVERLY BRIDGE
* 13
* 9
* 6
CELANESE/UNIROYAL/FIBERGLASS
908.2
BREMNER SEWAGE LAGOON
9309.3
763.8
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
* 11
* 10
* 9
SHERRITT GORDON
181.4
12.6
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
512.4
UNION CARBIDE
5.0
15 984.0
STURGEON RIVER
DOW CHEMICAL
2199.0
DIAMOND SHAMROCK
123.8
BEAVERHILL CREEK
1382.4
1866.2
REDWATER RIVER
VINCA
* 13
* 14
* 13
2921.2
ESSO CHEMICALS
PAKAN
* 12
* 12
* 12

TOTAL TRIBUTARY LOAD = 23 500.8
TOTAL INDUSTRIAL LOAD = 6 678.4
TOTAL MUNICIPAL LOAD = 32 130.5

TOTAL DAILY LOAD = 62 309.7

Fig. 8.4 Diagrammatic representation of Aug. 3-4/83 sodium concentrations ($mg \cdot L^{-1}$) and estimated municipal, tributary and industrial point source loadings ($kg \cdot d^{-1}$).

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to a mass increase of approximately 60,912 kg. The breakdown of measured industrial, municipal, and tributary loads for these dates is as follows:

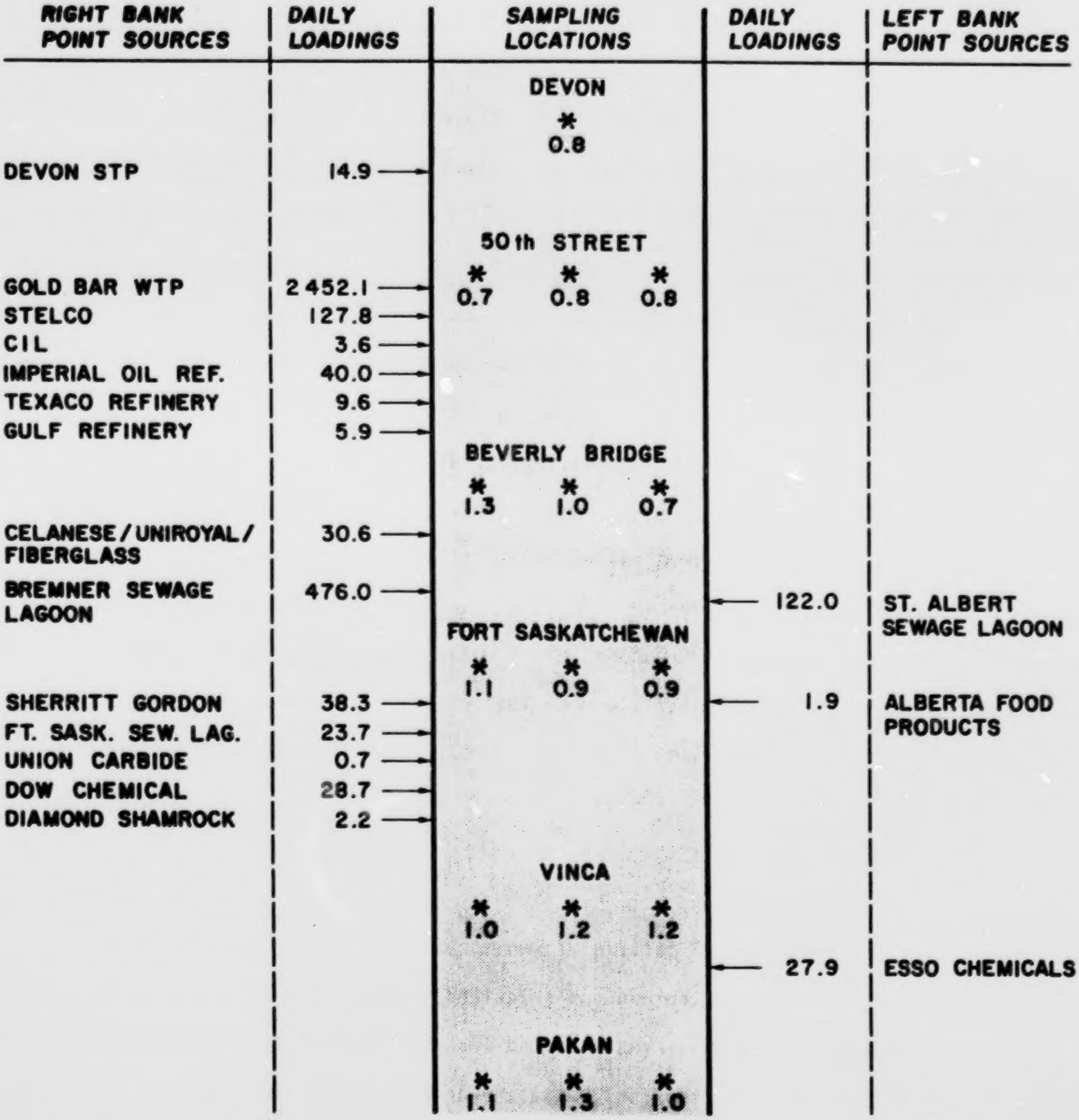
Industrial	8,063.4	kg·d^{-1}
Municipal	31,799.5	kg·d^{-1}
Tributaries	23,500.8	kg·d^{-1}
Total	63,363.7	kg·d^{-1}

Thus, the total measured sodium input for these dates closely approximated the change in river sodium mass. The importance of municipal wastewater treatment plant sodium discharges was relatively less (52.2%) than comparable municipal chloride discharges because of the high sodium loadings from tributaries, particularly the Sturgeon River.

8.1.3 Potassium

The longitudinal pattern of median potassium concentrations (Fig. 8.5) was similar to those of chloride and sodium. The first elevation in median concentration was detected for right-bank samples at the Beverly Bridge. At the Fort Saskatchewan Bridge and locations downstream, concentrations were greater than those upstream, but transverse variability was indicated by the data.

The average daily loading of potassium for the various continuous point sources has been estimated at 3405.9 kg·d^{-1}, which is a much smaller mass loading to the river than was the case for either


RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
* 0.8
DEVON STP
14.9
50th STREET
* 0.7
* 0.8
* 0.8
GOLD BAR WTP
2 452.1
STELCO
127.8
CIL
3.6
IMPERIAL OIL REF.
40.0
TEXACO REFINERY
9.6
GULF REFINERY
5.9
BEVERLY BRIDGE
* 1.3
* 1.0
* 0.7
CELANESE / UNIROYAL / FIBERGLASS
30.6
BREMNER SEWAGE LAGOON
476.0
122.0
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
* 1.1
* 0.9
* 0.9
SHERRITT GORDON
38.3
1.9
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
23.7
UNION CARBIDE
0.7
DOW CHEMICAL
28.7
DIAMOND SHAMROCK
2.2
VINCA
* 1.0
* 1.2
* 1.2
27.9
ESSO CHEMICALS
PAKAN
* 1.1
* 1.3
* 1.0

TOTAL INDUSTRIAL LOAD	=	302.7
TOTAL MUNICIPAL LOAD	=	3 103.2
TOTAL DAILY LOAD	=	3 405.9

Fig. 8.5 Diagrammatic representation of 1983-84 median potassium concentrations (mg · L^{-1}) and estimated municipal and industrial point source loadings (kg · d^{-1}) .

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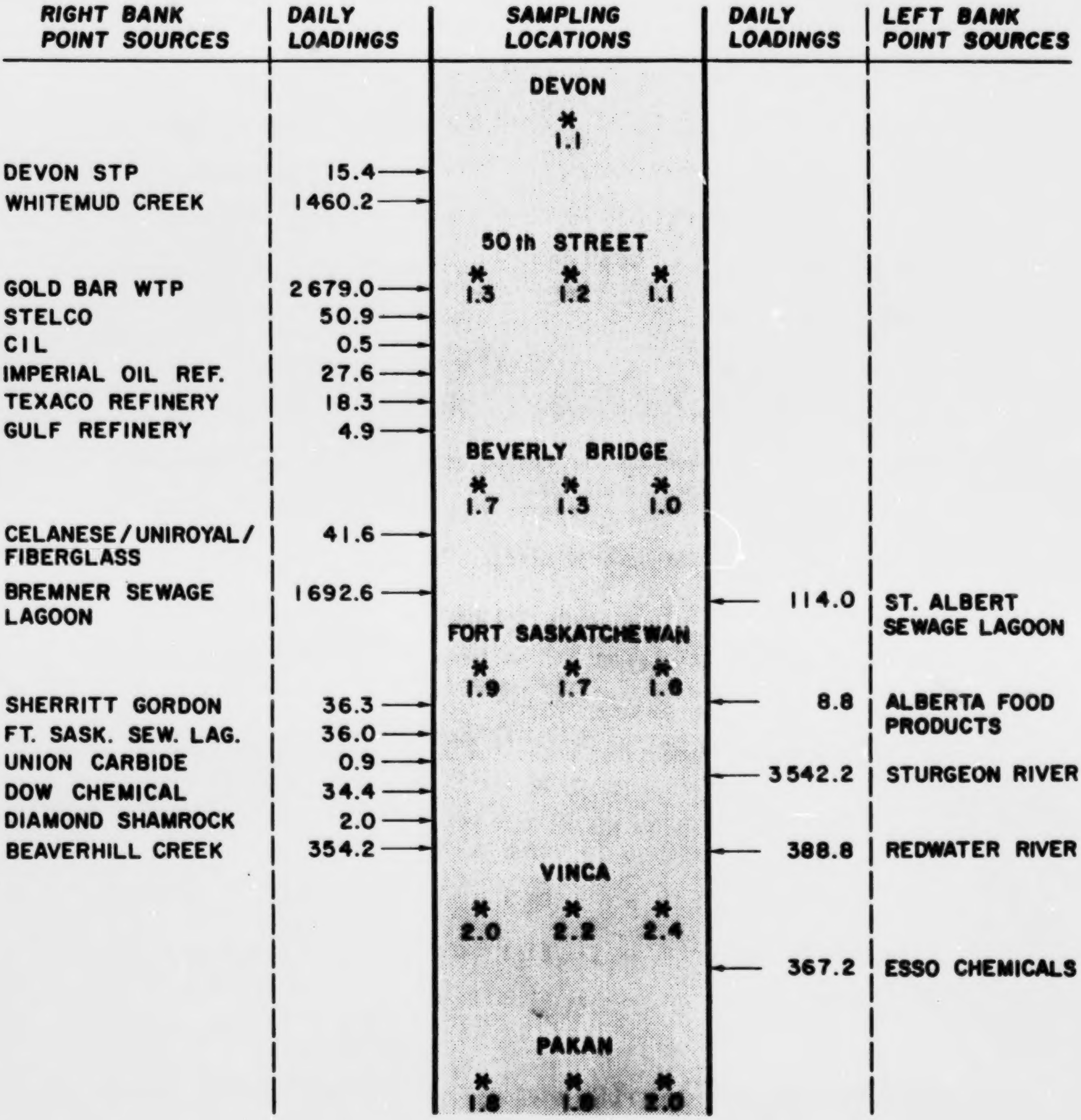
sodium or chloride (see Tables 8.2 and 8.3). Of this amount, the GBWTP contributed approximately 72.0%. In comparison to these estimates of daily municipal and industrial loadings, the Sturgeon River and the other three tributaries contributed relatively large amounts on those dates for which data were available (Table 8.4).

The detailed potassium concentration and loading data for August 3-4, 1983 are presented in Figure 8.6. The concentration pattern was similar to that portrayed by the median data in all but one important aspect. Although the first elevation in concentration was detected in the right-bank sample at Beverly Bridge, the highest overall concentration was detected at the left-bank sample from Vinca Bridge. These concentration data suggested an important left-bank source of potassium.

The breakdown of measured potassium loadings was as follows:

Industrial	302.6	$kg \cdot d^{-1}$
Municipal	3,103.3	$kg \cdot d^{-1}$
Tributaries	5,745.3	$kg \cdot d^{-1}$
Total	9,151.3	$kg \cdot d^{-1}$

Unlike the sodium and chloride loadings, most of the potassium loading on August 3-4, 1983 was derived from tributaries (62.8%), particularly from the Sturgeon River, which apparently determined the left-bank concentration at Vinca Bridge.


RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
*
1.1
DEVON STP
15.4
WHITEMUD CREEK
1460.2
50th STREET
* 1.3
* 1.2
* 1.1
GOLD BAR WTP
2679.0
STELCO
50.9
CIL
0.5
IMPERIAL OIL REF.
27.6
TEXACO REFINERY
18.3
GULF REFINERY
4.9
BEVERLY BRIDGE
* 1.7
* 1.3
* 1.0
CELANESE/UNIROYAL/FIBERGLASS
41.6
BREMNER SEWAGE LAGOON
1692.6
114.0
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
* 1.9
* 1.7
* 1.8
SHERRITT GORDON
36.3
8.8
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
36.0
UNION CARBIDE
0.9
3542.2
STURGEON RIVER
DOW CHEMICAL
34.4
DIAMOND SHAMROCK
2.0
BEAVERHILL CREEK
354.2
388.8
REDWATER RIVER
VINCA
* 2.0
* 2.2
* 2.4
367.2
ESSO CHEMICALS
PAKAN
* 1.8
* 1.8
* 2.0

TOTAL TRIBUTARY LOAD = 5745.4
TOTAL INDUSTRIAL LOAD = 593.4
TOTAL MUNICIPAL LOAD = 4537.0

TOTAL DAILY LOAD = 10875.8

Fig. 8.6 Diagrammatic representation of Aug. 3-4/83 potassium concentrations (mg · L⁻¹) and estimated municipal, tributary and industrial point source loadings (kg · d⁻¹) .

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8.1.4 Storm Sewers and Snow Dumps

In concluding the results and discussion component of this section, it is appropriate to address briefly a number of important but transient sources of sodium, chloride, and potassium not previously quantified. These sources are the storm sewers (see Section 2.9) and the winter snow dumps, six of which have been located adjacent to or on the river (Fig. 2.5).

A preliminary investigation of storm-sewer runoff characteristics was conducted during March and April, 1982, in order to determine the influence of local spring runoff on river water quality (Reynoldson and Livingstone 1983). An analysis of diurnal loading patterns for sodium and chloride was performed and revealed that large daily inputs from the storm sewers upstream of the Rossdale Water Treatment Plant occurred. Estimated daily inputs for sodium and chloride on March 24, 1982, were 24998 kg and 37503 kg, respectively. A distinct seasonality in daily loading rates was evident also, with the highest inputs occurring during the period of maximum local snowmelt (late March) and subsiding thereafter.

Reports submitted to Alberta Environment as stipulated in the City's license to maintain snow dumps (City of Edmonton 1982, 1983) have been reviewed for the time period encompassed by the present study (i.e. winters of 1981-82 and 1982-83). These winters were vastly different in terms of snowfall: 1981-82 was a winter of extremely heavy snowfall; 1982-83 was a winter of such low snowfall accumulation that only one river dump was used. Typically, year-to-year variability characterizes these sources.

The 1981-82 data have revealed that masses of road salt and other materials were concentrated in the snow dump located at the Groat Road Bridge. In terms of the three major ions of interest, the estimated quantities were: chloride (72,912 kg), sodium (55,986 kg), potassium (3,949 kg). These estimates were based on the approximate volume of water stored in the dump and the results of replicated chemical sampling and analysis (City of Edmonton 1982). Thus, a considerable mass of materials was released to the river from this dump alone in 1981-82. However, the timing of the release coincided with high dilution capacity (median flow greater than 200 $m^3 \cdot s^{-1}$) resulting from local spring runoff. Previous studies (Renewable Resources 1974) have suggested that the bulk of the snow dump masses may disappear over a period of several days during the time of spring thaw and river ice break-up from mid April to late April.

Because the data collection program of the present river water quality study did not commence until May 18, 1982, the data set did not permit the examination of the influence of either spring storm-water runoff or snow dumps on river water quality. Because of the episodic nature of these inputs, a specially designed sampling program would be needed in order to evaluate river water quality during this short but critical period.

8.2 Surface Water Quality Objectives

Provincial objectives have not been specified for the major ions discussed in the preceding section. This is because they are often too variable in the natural state to permit the definition of absolute limits and because most are considered harmless even when present in moderately high concentrations (McNeely et al. 1979).

An objective of 10 $mg{\cdot}L^{-1}$ over background concentration has been set for suspended solids, or NFR. However, this objective is difficult to apply in any developed river basin since true background data (i.e. pre-settlement data) are usually unavailable. The only alternative is to make upstream-downstream comparisons on the assumption that the upstream data would be representative of pre-settlement conditions further downstream.

Based on this approach, comparisons were made between the NFR data sets at Devon and the other sampling locations for each sampling trip in 1982 and 1983. In sixty-three of 280 individual samples, downstream concentrations exceeded background concentrations by more than 10 $mg{\cdot}L^{-1}$, usually during high-flow events associated with rainfall or mountain snowmelt between mid-May and mid-July. Since high concentrations were found at locations throughout the Edmonton region and not just downstream of the GBWTP, the data suggest that city stormwater runoff was a major source of this material.

8.3 Impacts

Although measured concentrations of chloride, sodium, and potassium at Pakan were significantly higher than concentrations at Devon, they remained low overall, and the pattern of ionic dominance remained unchanged. No particular or general impacts are thought to accrue from these increases in major ion concentrations.

A significant elevation in suspended solid loads in the river within and downstream of Edmonton may contribute to changes in the biota. In general, an increase in suspended solids contributes to greater turbidity which reduces the transmission of photosynthetically active radiation. This could suppress the autotrophic primary production of planktonic and attached algae, as well as that of the macrophytic community. High suspended-solid loads also enhance the scouring capacity of a river. Indirectly, benthic invertebrates may be impacted by an increase in sedimentation and habitat alteration, by a decrease in photosynthetically produced food, and by the scouring of attached plant material. These impacts are discussed in more detail in Section 12 (Chlorophyll-a) and Part 2 (Vol. 2: Zoobenthos).

9.0 METALS

Sampling for metals was done in both the flowing water component and the sediment component. The sampling schedule for the water component included 11 mainstem North Saskatchewan River (NSR) locations on 12 dates in 1982, and 6 mainstem NSR locations on 12 dates in 1983 (Tables 4.4 and 4.5). On 5-6 October 1983, sediment sampling was done at 5 mainstem locations: at one site for each of two locations, and at sites on both banks for each of 3 locations, for a total of 8 sites.

Table 5.1 summarizes methods and detection limits for metals and other variables assessed in this study. Additional details of field methods, laboratory methods, and interpretation are given in Sections 5.1 to 5.4.

9.1 Results and Discussion: Metals

The following patterns of responses were identified for metals in the water component:

- measurements consistently below the analytical detection limit.
- present above detection limit, but no seasonal or longitudinal pattern.
- seasonal change only.
- longitudinal change only.
- both seasonal and longitudinal change.

The metals following these patterns are listed in Table 9.1.

TABLE 9.1 Summary of metal responses in the water phase, North Saskatchewan River, 1982-1983.

Not Detectable	Little or No Change	Temporal Change	Spatial Change	Temporal and Spatial Change
Mercury	Copper	Iron	Nickel	Manganese
Cadmium	Chromium	Aluminum	Lead	
Selenium	Vanadium		Zinc	
Molybdenum	Arsenic			
Cobalt				
Beryllium				

TABLE 9.2 Metals below detection limit, in the water phase, North Saskatchewan River, 1982-1983

	Detection Limit
Mercury	< 0.0001 mg•L^{-1}
Cadmium	< 0.0010 mg•L^{-1}
Selenium	< 0.0002 mg•L^{-1}
Molybdenum	< 0.0010 mg•L^{-1}
Cobalt	< 0.0010 mg•L^{-1}
Beryllium	< 0.0010 mg•L^{-1}

Six metals were below the analytical detection limit in all samples collected during this study (Table 9.2). Among the six metals were mercury and cadmium which, along with most of their compounds, are known to have toxic effects on humans and on aquatic life (McNeely et al. 1979).

Four metals showed little or no change in concentration during the course of this study: copper, chromium, vanadium, arsenic. Median values and ranges for the Devon, Fort Saskatchewan, and Pakan locations are summarized in Table 9.3. Although some of these metals or their compounds are known to have toxic effects at much higher concentrations, values found were generally well below those likely to cause adverse effects on human or aquatic life (Alberta Environment 1977).

Iron and aluminum exhibited strong seasonal but little spatial change throughout this study. This response is linked to seasonal variations in flow, as demonstrated by a positive relationship between flow and concentration. This relationship stems from erosion during runoff and the subsequent transport of suspended materials by the river, a well known natural phenomenon. Figure 9.1 is a seasonal plot for iron at two locations, 50th Street Footbridge and Pakan. Figure 9.2 is a seasonal plot for aluminum at the Beverly Bridge location.

Iron and aluminum occur naturally in the rocks and soils of the NSR drainage basin; there are no identifiable point sources and most loading is natural.

TABLE 9.3 Metal showing little or no change, in the water phase, North Saskatchewan River, 1982-1983. Values are $mg \cdot L^{-1}$.

	DEVON*		FORT SASKATCHEWAN**		PAKAN**	
	Median	Range	Median	Range	Median	Range
Copper	0.003	(0.001-0.016)	0.003	(0.001-0.024)	0.002	(0.001-0.016)
Chromium	0.004	(0.001-0.044)	0.004	(0.001-0.007)	0.004	(0.001-0.005)
Vanadium	0.003	(0.002-0.010)	0.004	(0.002-0.009)	0.003	(0.002-0.013)
Arsenic	0.0004	(0.0002-0.0011)	0.0005	(0.0002-0.0015)	0.0005	(0.0002-0.002)

* Composite samples.
** Centre site samples.

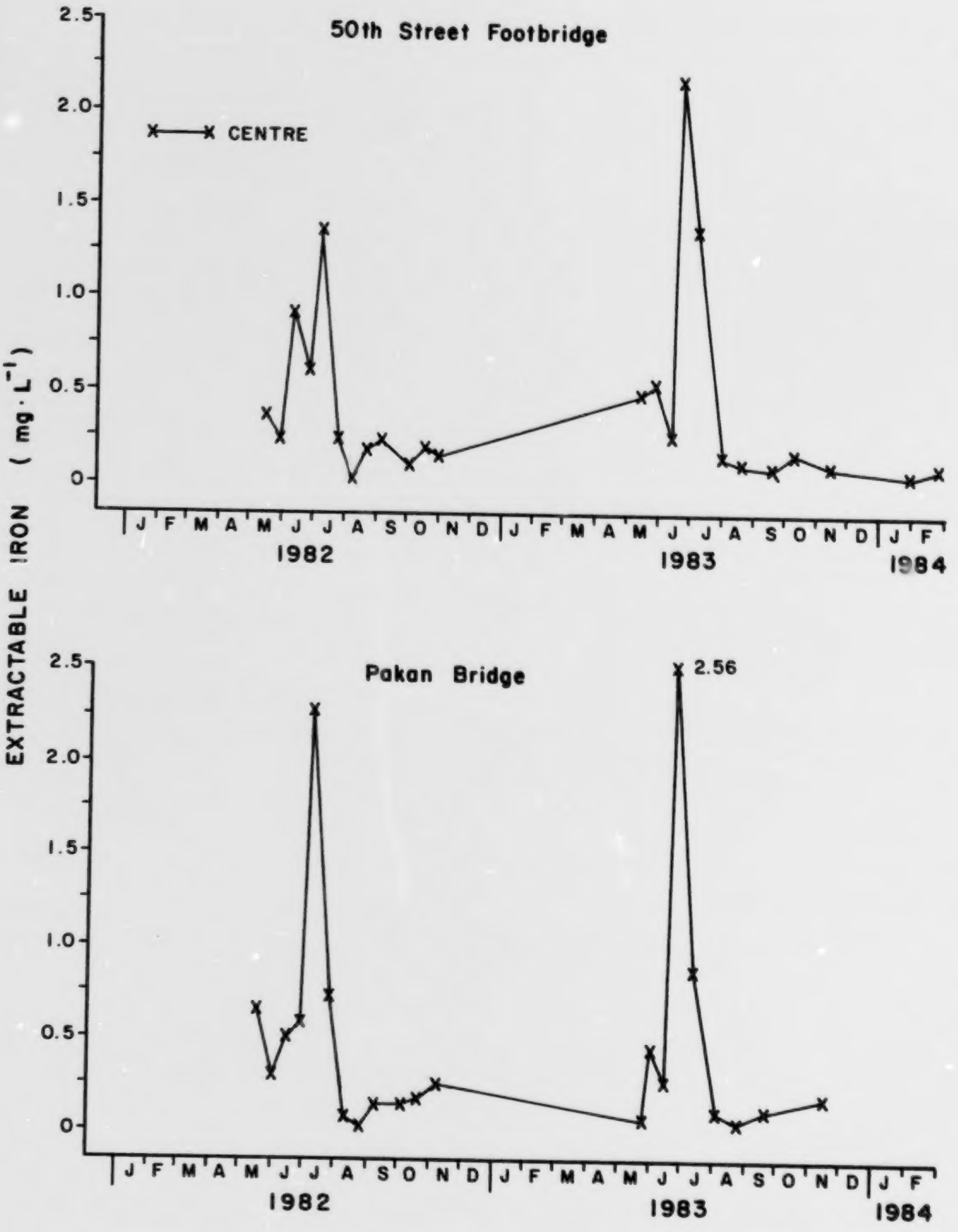

Fig. 9.1 Extractable iron at two NSR study locations, 1982-1983 .

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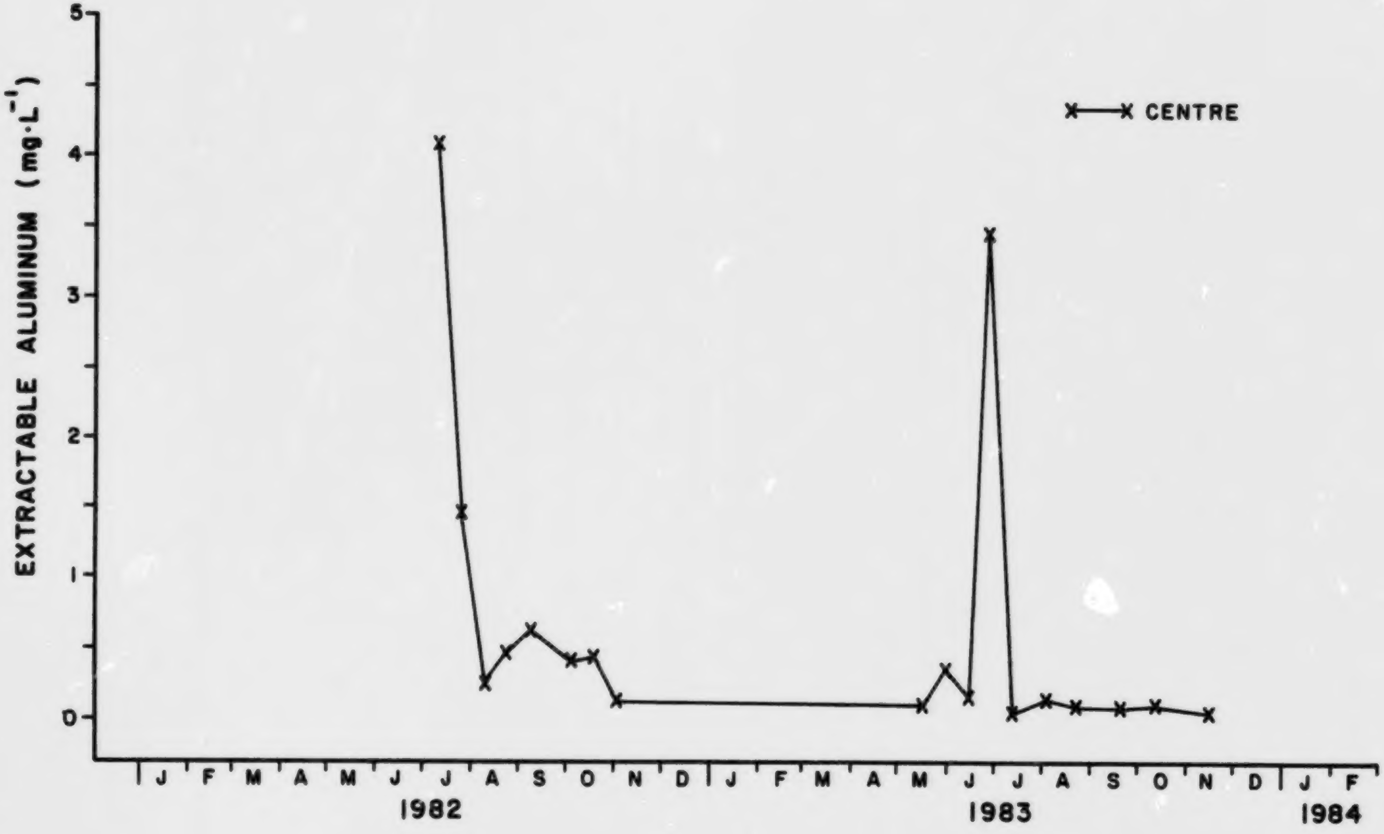

Fig. 9.2 Extractable aluminum at the Beverly bridge location, NSR, 1982-1983.

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Manganese was the only metal which showed both seasonal and spatial changes over the sampling period. The prevailing trend for manganese was seasonal, and concentrations were associated with the transportation of eroded sediments during high flow periods (Fig. 9.3). The spatial effect was rather small and probably natural (Table 9.4). However, there was evidence of a small contribution from the Gold Bar Wastewater Treatment Plant (GBWTP - Fig. 9.4).

Manganese is similar to iron in chemical behavior and most commonly associated with it. Soils, sediments, and various metamorphic and sedimentary rocks are the usual sources of naturally occurring manganese, which seldom exceeds concentrations of 1.0 $mg{\cdot}L^{-1}$ in natural surface waters (McNeely et al. 1979). However, this metal is commonly used in industry and high loads in surface waters can be caused by industrial waste discharge or acid-mine drainage.

Lead and nickel showed small but definite spatial change. Changes in zinc concentrations were rather sporadic, although there was some evidence of increase in downstream direction. The longitudinal plots for lead and nickel are given in Figure 9.5.

In the case of nickel, right-bank sites showed increasing concentrations, whereas centre-channel and left-bank sites showed little or no change. The right-bank increase is due to industrial input in the Fort Saskatchewan area (Fig. 9.6). At Pakan, where the river is well mixed, the overall increase in nickel concentration was about 0.002 $mg.L^{-1}$, which matches the input loading.

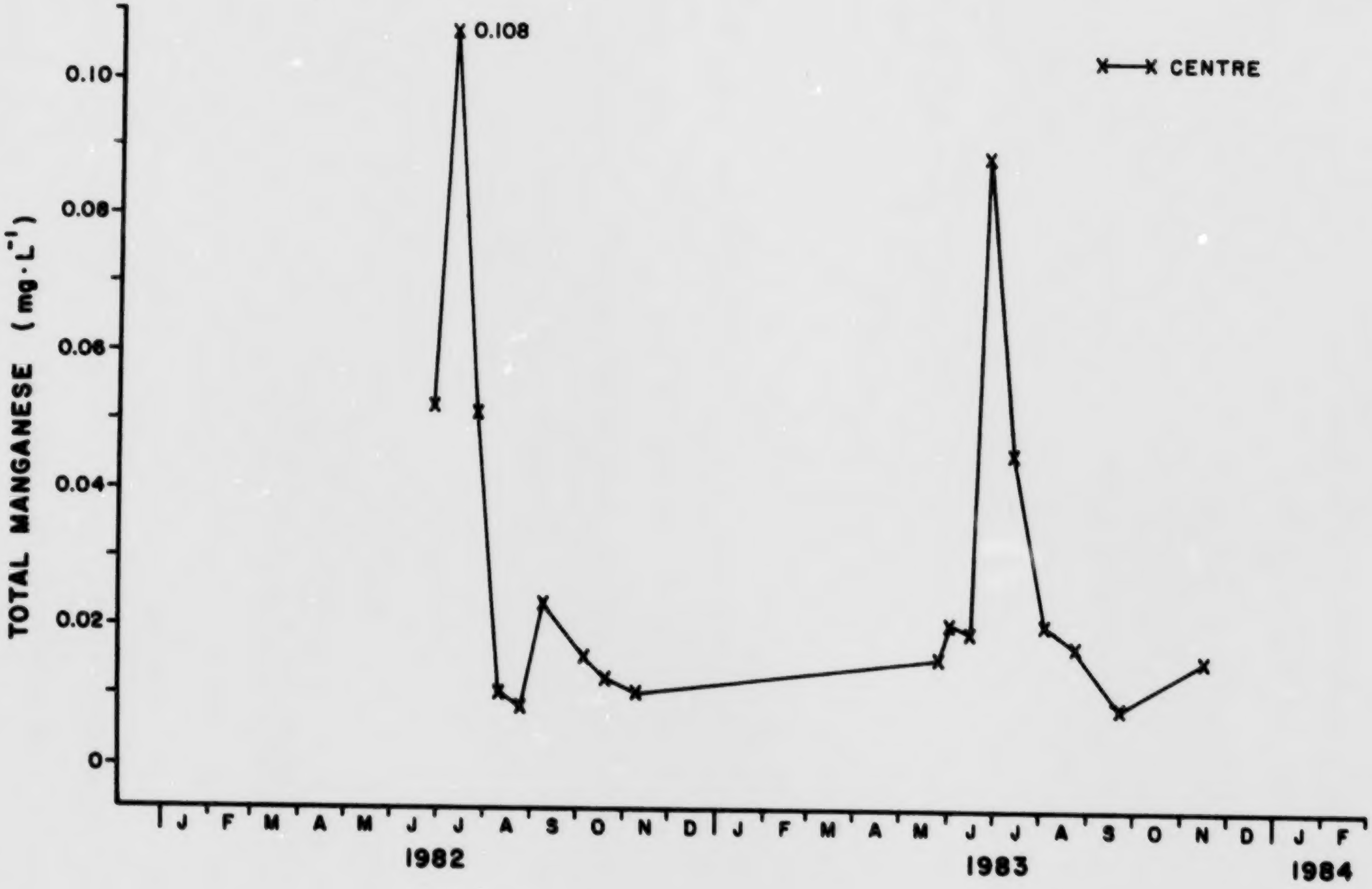

Fig. 9.3 Total manganese at Pakan bridge, NSR, 1982-1983.

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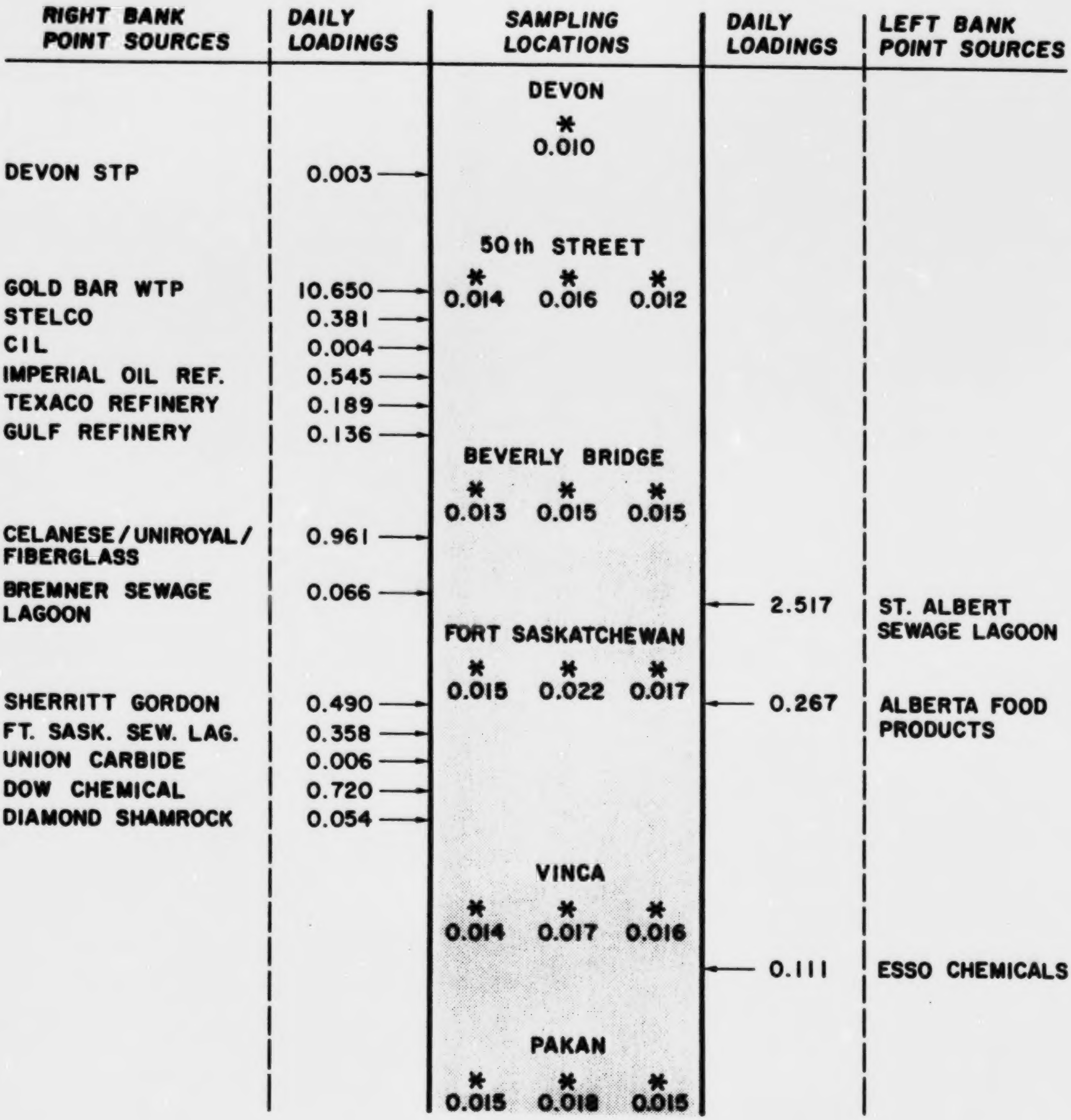
TABLE 9.4. Manganese in the water phase, North Saskatchewan River, 1982-1983. Median and (range) values are mg•L^{-1}.

Location	Sites		
	Left Bank	Centre	Right Bank
Devon Bridge	-	0.010 (0.008-0.087)*	-
E. L. Smith WTP	-	0.012 (0.008-0.084)*	-
Rossdale WTP	0.015 (0.008-0.106)	0.011 (0.008-0.099)	0.015 (0.008-0.121)
50th Street Footbridge	0.014 (0.008-0.098)	0.016 (0.008-0.106)	0.012 (0.008-0.121)
Rundle Park Footbridge	0.012 (0.088-0.450)	0.010 (0.008-0.120)	0.012 (0.008-0.119)
Beverly Bridge	0.013 (0.008-0.135)	0.015 (0.008-0.114)	0.015 (0.008-0.119)
Clover Bar	0.016 (0.009-0.110)	0.013 (0.009-0.120)	0.018 (0.013-0.113)
Fort Saskatchewan	0.015 (0.008-0.092)	0.022 (0.008-0.094)	0.017 (0.009-0.093)
Sturgeon NSR Confluence	0.019 (0.013-0.115)	0.019 (0.008-0.100)	0.020 (0.011-0.107)
Vinca Bridge	0.014 (0.009-0.106)	0.017 (0.008-0.122)	0.016 (0.009-0.119)
Pakan Bridge	0.015 (0.008-0.117)	0.018 (0.008-0.108)	0.015 (0.008-0.124)

*composite sample


RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
0.010
DEVON STP
0.003
50th STREET
GOLD BAR WTP
10.650
0.014
0.016
0.012
STELCO
0.381
CIL
0.004
IMPERIAL OIL REF.
0.545
TEXACO REFINERY
0.189
GULF REFINERY
0.136
BEVERLY BRIDGE
0.013
0.015
0.015
CELANESE / UNIROYAL / FIBERGLASS
0.961
BREMNER SEWAGE LAGOON
0.066
2.517
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
0.015
0.022
0.017
SHERRITT GORDON
0.490
0.267
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
0.358
UNION CARBIDE
0.006
DOW CHEMICAL
0.720
DIAMOND SHAMROCK
0.054
VINCA
0.014
0.017
0.016
0.111
ESSO CHEMICALS
PAKAN
0.015
0.018
0.015

TOTAL INDUSTRIAL LOAD = 3.867
TOTAL MUNICIPAL LOAD = 13.591
TOTAL DAILY LOAD = 17.458

Fig. 9.4 Diagrammatic representation of 1982-84 median manganese concentrations ($mg \cdot L^{-1}$) and estimated municipal and industrial point source loadings ($kg \cdot d^{-1}$) .

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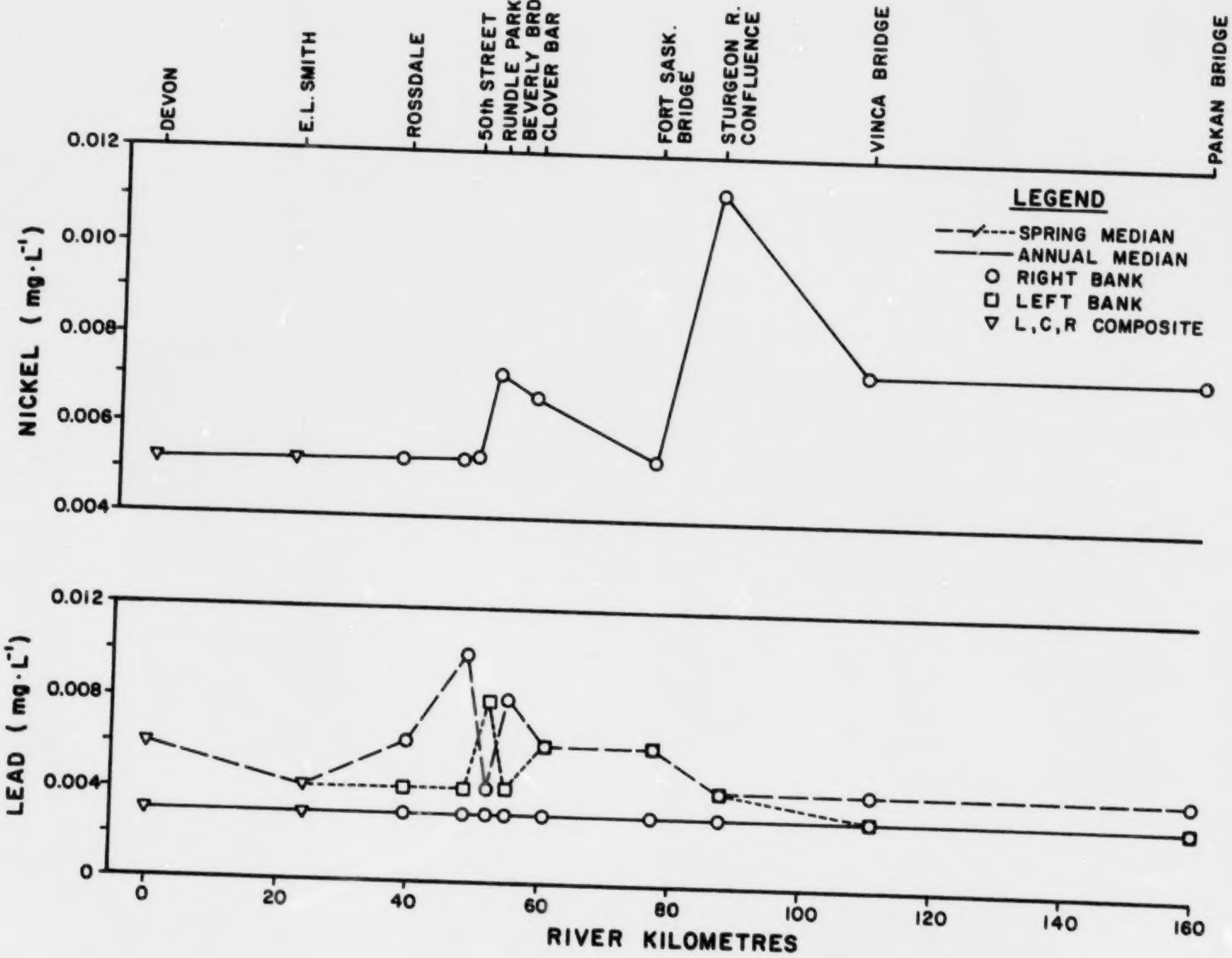

Fig. 9.5 Median concentrations of nickel and lead, NSR, 1982-1983.

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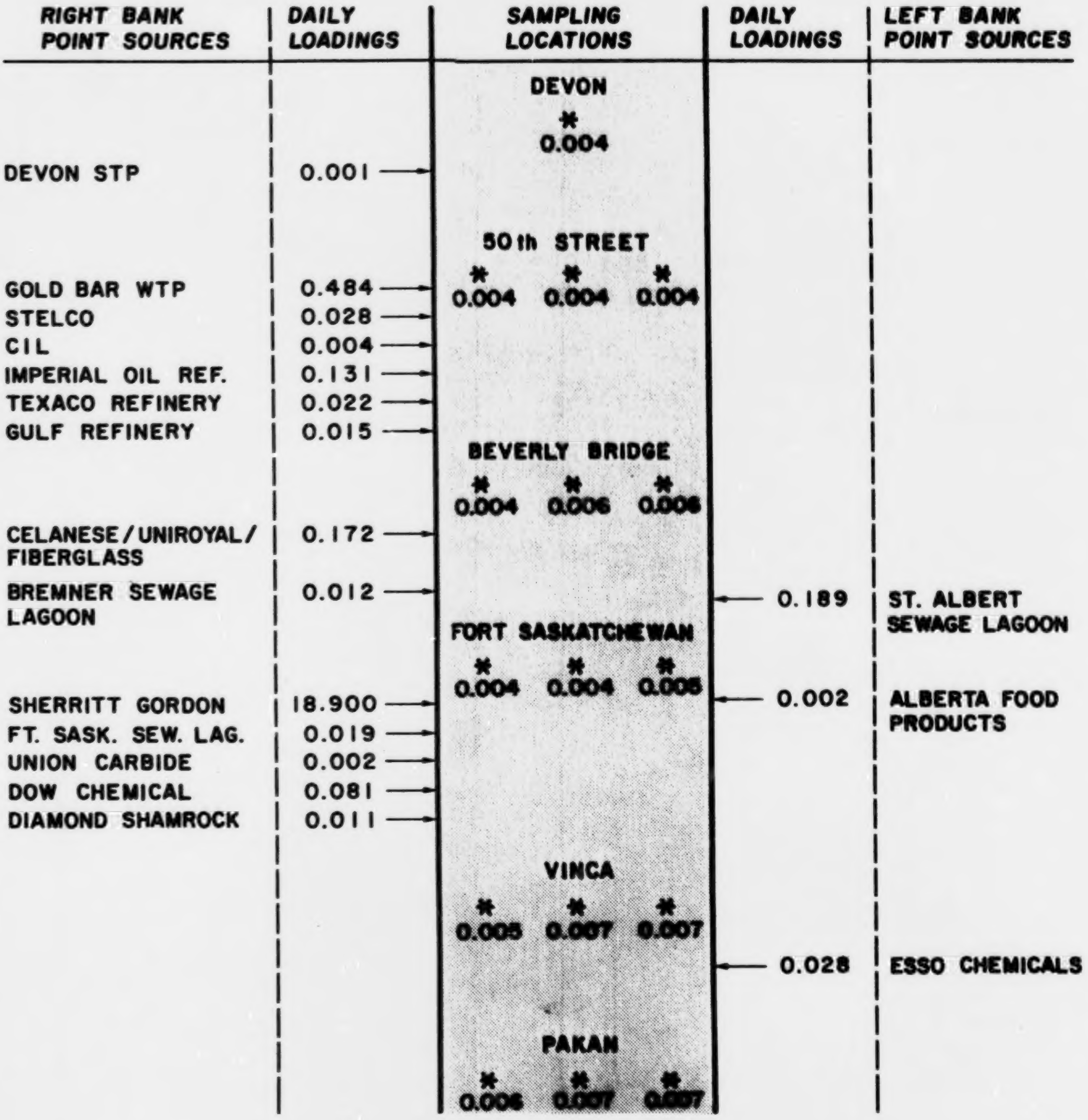
RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
0.004
DEVON STP
0.001
50th STREET
0.004 0.004 0.004
GOLD BAR WTP
0.484
STELCO
0.028
CIL
0.004
IMPERIAL OIL REF.
0.131
TEXACO REFINERY
0.022
GULF REFINERY
0.015
BEVERLY BRIDGE
0.004 0.006 0.006
CELANESE/UNIROYAL/FIBERGLASS
0.172
BREMNER SEWAGE LAGOON
0.012
0.189
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
0.004 0.004 0.005
SHERRITT GORDON
18.900
0.002
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
0.019
UNION CARBIDE
0.002
DOW CHEMICAL
0.081
DIAMOND SHAMROCK
0.011
VINCA
0.005 0.007 0.007
0.028
ESSO CHEMICALS
PAKAN
0.006 0.007 0.007

TOTAL INDUSTRIAL LOAD = 19.396
TOTAL MUNICIPAL LOAD = 0.705

TOTAL DAILY LOAD = 20.101

Fig. 9.6 Diagrammatic representation of 1982-84 median nickel concentrations (mg·L^{-1}) and estimated municipal and industrial point source loadings (kg·d^{-1}) .

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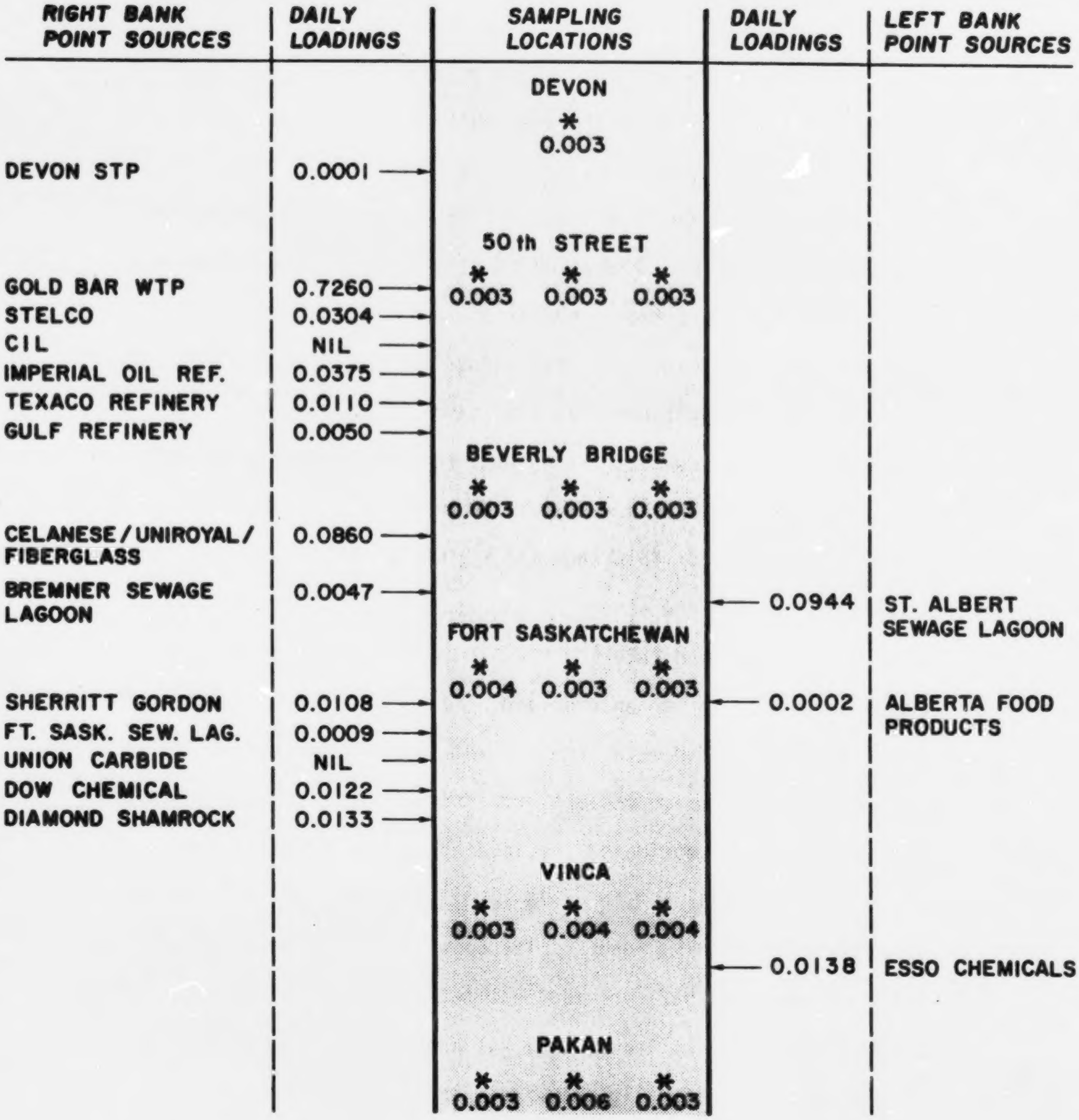
Although nickel is relatively inert, it is seldom found in its native state. Most naturally occurring nickel in the aquatic environment is leached from igneous rocks. Anthropogenic sources include gases from the burning of fossil fuels and the incineration of wastes, and effluents from a number of industrial processes.

As shown in Figure 9.5, lead showed small but definite increases in left-bank and right-bank concentrations in the Edmonton area. Annual median lead concentrations upstream of Edmonton at Devon were virtually the same as those downstream of Edmonton at Pakan where the river is well mixed. This suggests either assimilation in the study section of the NSR downstream of Edmonton, or a small total input (Fig. 9.7). The lead entering the NSR in the Edmonton area was undoubtedly of anthropogenic origin, and most of it probably came from the burning of leaded motor fuels. The lead likely entered the river via storm sewers, which collect urban street runoff. Reynoldson and Livingstone (1983) estimated the loading of lead from all sewers upstream of Rossdale WTP to be 73 $kg.d^{-1}$ and 15 $kg.d^{-1}$ for two dates during the 1982 spring runoff. The snow disposal report for 1981-1982 (City of Edmonton 1982) provided estimates for total lead contained in two snow dumps: Groat Road (205.7 kg) and 105th Street (166.7 kg).

Lead occurs naturally and widely in the environment and occurs in both soluble and suspended forms. However, natural waters seldom contain high levels of lead. The input of lead from human activities usually exceeds all natural sources (McNeely _et al_. 1979).


RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
* 0.003
DEVON STP
0.0001
50th STREET
* 0.003
* 0.003
* 0.003
GOLD BAR WTP
0.7260
STELCO
0.0304
CIL
NIL
IMPERIAL OIL REF.
0.0375
TEXACO REFINERY
0.0110
GULF REFINERY
0.0050
BEVERLY BRIDGE
* 0.003
* 0.003
* 0.003
CELANESE / UNIROYAL / FIBERGLASS
0.0860
BREMNER SEWAGE LAGOON
0.0047
0.0944
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
* 0.004
* 0.003
* 0.003
SHERRITT GORDON
0.0108
0.0002
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
0.0009
UNION CARBIDE
NIL
DOW CHEMICAL
0.0122
DIAMOND SHAMROCK
0.0133
VINCA
* 0.003
* 0.004
* 0.004
0.0138
ESSO CHEMICALS
PAKAN
* 0.003
* 0.006
* 0.003

TOTAL INDUSTRIAL LOAD = 0.2202
TOTAL MUNICIPAL LOAD = 0.8261
TOTAL DAILY LOAD = 1.0463

Fig. 9.7 Diagrammatic representation of 1982-84 median lead concentrations ($mg \cdot L^{-1}$) and estimated municipal and industrial point source loadings ($kg \cdot d^{-1}$) .

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Anthropogenic sources include emissions from internal combustion engines, smelting, refining, and many other manufacturing activities, and effluents from a wide spectrum of industries using lead salts.

Median values and the range of values for zinc fluctuated considerably and did not show a clear longitudinal trend (Table 9.5), although the number of high values increased in downstream direction (see Table 9.6, section 9.2). The loading summary identifies two point sources responsible for contributing most of the total load: Gold Bar Wastewater Treatment Plant and Sherritt Gordon (Fig. 9.8).

Zinc occurs naturally in the environment, but high levels (i.e. > 0.05 mg.L^{-1}) are usually associated with human, industrial and domestic activities. The total zinc levels determined in the NSR were somewhat higher than those reported for other rivers in Alberta (e.g. Blachford and Ongley 1984) or elsewhere in Canada (e.g. Environment Canada 1981, Kuntz 1984). However, most of the load was apparently natural (cf. levels at Devon Bridge). The fraction of total zinc in dissolved form is quite low at high pH levels, such as occur in the NSR; the dissolved fraction increases rapidly as pH levels drop below 7 (Shiller and Boyle 1985).

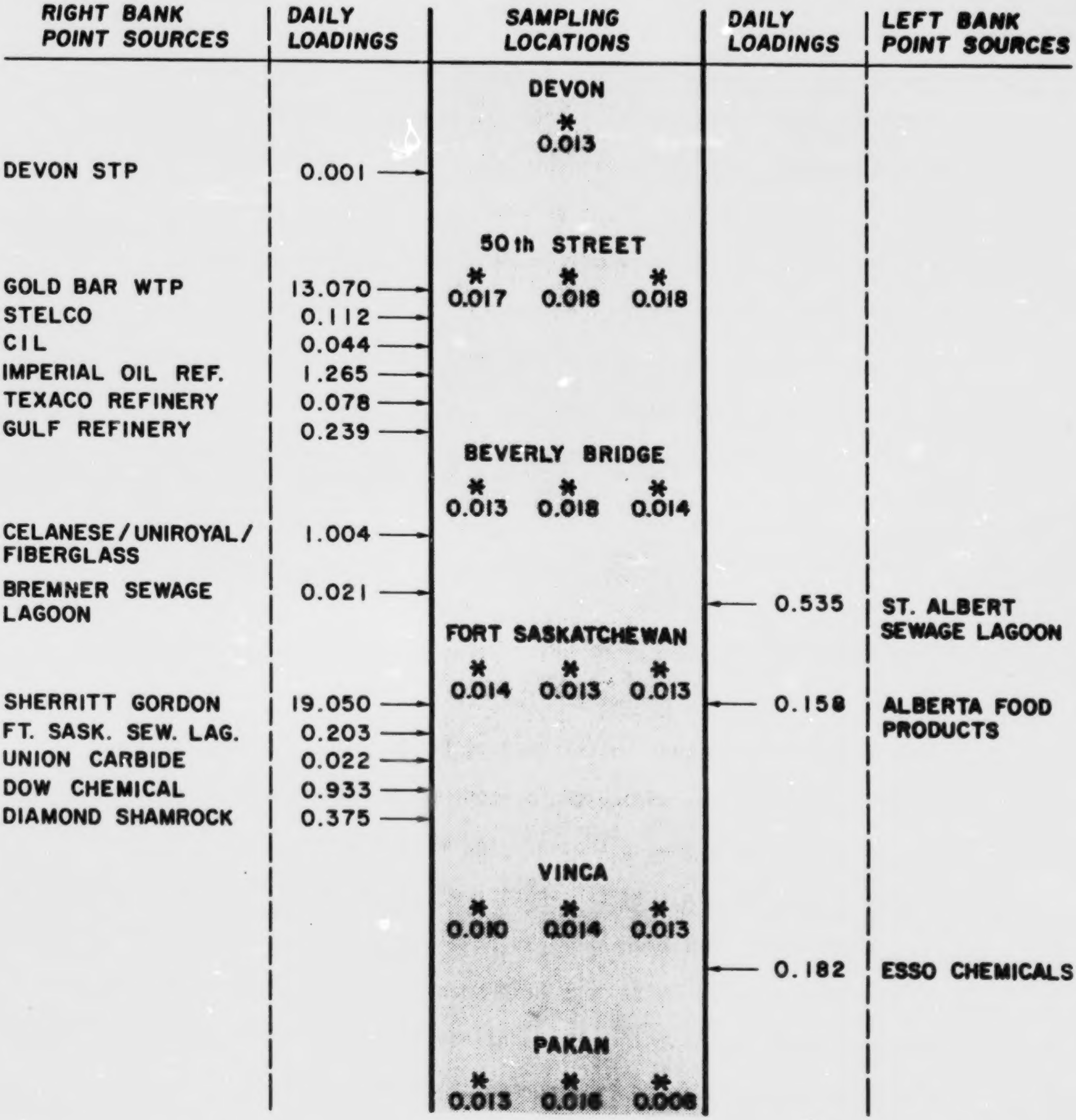
9.2 Surface Water Quality Objectives

The measured values for metals were compared with both Alberta Surface Water Quality Objectives (ASWQO, Alberta Environment 1977) or with Guidelines for Surface Water Quality (Environment Canada 1979)

TABLE 9.5 Zinc in the water phase, North Saskatchewan River, 1982-1983. Median and (range) values are mg•L^{-1}.

Location	Sites		
	Left Bank	Centre	Right Bank
Devon Bridge	-	0.013 (0.001-0.043)*	-
E. L. Smith WTP	-	0.029 (0.001-0.048)*	-
Rossdale WTP	0.029 (0.001-0.042)	0.023 (0.001-0.156)	0.031 (0.014-0.045)
50th Street Footbridge	0.017 (0.002-0.058)	0.018 (0.001-0.048)	0.018 (0.001-0.069)
Rundle Park Footbridge	0.034 (0.003-0.050)	0.037 (0.017-0.073)	0.031 (0.015-0.048)
Beverly Bridge	0.013 (0.001-0.054)	0.018 (0.001-0.045)	0.014 (0.004-0.065)
Clover Bar	0.036 (0.001-0.050)	0.028 (0.012-0.062)	0.037 (0.002-0.058)
Fort Sask. Bridge	0.014 (0.001-0.057)	0.013 (0.011-0.055)	0.013 (0.003-0.064)
Sturgeon NSR Confluence	0.023 (0.006-0.064)	0.021 (0.002-0.043)	0.037 (0.017-0.057)
Vinca Bridge	0.010 (0.001-0.046)	0.014 (0.001-0.053)	0.013 (0.003-0.051)
Pakan Bridge	0.013 (0.003-0.041)	0.016 (0.001-0.057)	0.008 (0.001-0.054)

*composite sample


RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
* 0.013
DEVON STP
0.001
50th STREET
* 0.017
* 0.018
* 0.018
GOLD BAR WTP
13.070
STELCO
0.112
CIL
0.044
IMPERIAL OIL REF.
1.265
TEXACO REFINERY
0.078
GULF REFINERY
0.239
BEVERLY BRIDGE
* 0.013
* 0.018
* 0.014
CELANESE / UNIROYAL / FIBERGLASS
1.004
BREMNER SEWAGE LAGOON
0.021
0.535
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
* 0.014
* 0.013
* 0.013
SHERRITT GORDON
19.050
0.158
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
0.203
UNION CARBIDE
0.022
DOW CHEMICAL
0.933
DIAMOND SHAMROCK
0.375
VINCA
* 0.010
* 0.014
* 0.013
0.182
ESSO CHEMICALS
PAKAN
* 0.013
* 0.016
* 0.008

TOTAL INDUSTRIAL LOAD = 23.462
TOTAL MUNICIPAL LOAD = 13.830

TOTAL DAILY LOAD = 37.292

Fig. 9.8 Diagrammatic representation of 1982-84 median zinc concentrations ($mg \cdot L^{-1}$) and estimated municipal and industrial point source loadings ($kg \cdot d^{-1}$) .

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when no ASWQO criteria exist. Measured values in excess of the Objectives were treated as exceedences.

Most metal concentrations determined during this study were at levels falling within the ASWQO; some could not be considered to exceed limits because natural concentrations exceed ASWQO criteria. Six metals were below the analytical detection limits and, therefore, were within the ASWQO guidelines (mercury, cadmium, selenium, molybdenum, cobalt, and beryllium). Four metals (copper, chromium, arsenic, and vanadium) occurred above the detection limit, but were within the ASWQO guidelines.

There are no Alberta or federal surface or drinking water objectives for aluminum or nickel. However, concentrations of nickel should be less than 0.025 $mg.L^{-1}$ for the protection of sensitive aquatic life (Great Lakes Water Quality Board 1976). Nickel was within this guideline during the present study. The oral toxicity of nickel is extremely low, although a few medical conditions have been linked to very high nickel concentrations in air or water.

Aluminum has not been shown to pose a hazard to human health, and so no drinking water guidelines have been set. It is recommended that water supplies for livestock contain less than 5 $mg.L^{-1}$ to avoid potential adverse affects (Environmental Studies Board 1973).

For three metals (iron, manganese and zinc), natural levels approached or exceeded the ASWQO criteria. No adverse health problems have been associated with naturally occurring iron concentrations, but high concentrations are considered objectionable for drinking water or industrial purposes because of taste, discoloration, scaling and iron-bacteria problems. High iron concentrations may contribute to precipitation problems which adversely affect aquatic life. A criterion level of 0.300 $mg.L^{-1}$ has generally been proposed for the protection of aquatic life and the assurance of quality surface water (Great Lakes Water Quality Board 1976, Alberta Environment 1977).

Manganese is an essential element for the nutrition of humans and most other life forms. It is unlikely that levels in surface waters ever reach toxic levels for livestock, so no criteria have been set. Established criteria for drinking water (Department of National Health and Welfare 1969) or surface waters (Alberta Environment 1977) of 0.05 $mg.L^{-1}$ are based mainly on aesthetic considerations, particularly taste.

Zinc complied with the ASWQO criteria in 478 of 500 samples. The few exceedences were scattered among all study locations except Devon and E.L. Smith (Table 9.6). However, maximum levels at these two upstream locations were very close to the ASWQO of 0.05 $mg.L^{-1}$. Although the pattern was not entirely clear, contributions from municipal wastewater treatment plants (particularly GBWTP) and industries (particularly Sherritt Gordon) were likely the reason for some of the exceedences (see Table 9.5). The occurrence of sporadic exceedences upstream of major municipal or industrial discharges (i.e. 50th Street Footbridge and Rossdale WTP) implicated stormsewers and the urban surface runoff which they carry.

TABLE 9.6 Zinc in the water phase, North Saskatchewan River, 1982-1983; comparison of results with Alberta Surface Water Quality Objectives.*

Location	Number of values complying with objectives	Maximum Level ($mg \bullet L^{-1}$)
Devon Bridge	24/24	0.043
E. L. Smith WTP	12/12	0.048
Rossdale WTP	35/36	0.156
50th Street Footbridge	61/64	0.069
Rundle Park Footbridge	33/36	0.073
Beverly Bridge	69/70	0.065
Clover Bar	33/36	0.062
Fort Saskatchewan Bridge	49/55	0.064
Sturgeon-NSR confluence	32/33	0.064
Vinca Bridge	66/67	0.051
Pakan Bridge	64/67	0.057
Total	478/500	

*Objective for zinc is 0.05 $mg \bullet L^{-1}$.

Zinc is relatively non-toxic to humans, even at levels many times as high as those determined in the NSR in 1982-1983 (McNeely et al. 1979). Most terrestrial animals can tolerate high levels of zinc in their drinking water (Environmental Studies Board 1973). Many aquatic organisms, especially fish, are sensitive to low zinc concentrations, but toxicity varies considerably depending on pH levels, water hardness, and the presence of other metals. Many studies concerning potential zinc toxicity are reviewed by Taylor and Demayo (1980).

Lead was the only metal which had concentrations exceeding the ASWQO criteria and which could be attributed mainly to non-natural sources. There were only seven exceedences compared to 310 compliances, and all exceedences were in the Edmonton-Fort Saskatchewan portion of the NSR study section (Table 9.7). They occurred mainly during spring and in the poorly mixed part of the NSR downstream of the greater Edmonton area (see section 3.0). The highest level detected was 0.112 $mg.L^{-1}$. All lead levels measured upstream of Rossdale or downstream of Fort Saskatchewan complied with the ASWQO.

The bioaccumulation of lead by living organisms has become a cause for concern in recent years. Lead is a toxic material and can accumulate in the bones of humans and animals. The toxic effect of lead on fish is reported to decrease as hardness and dissolved oxygen increase, a clear example of the interrelationships which govern the ultimate effects of many variables in the aquatic environment. Usually, aquatic criteria are more stringent than those set for

TABLE 9.7 Lead in the water phase, North Saskatchewan River, 1982-1983; comparison of results with Alberta Surface Water Quality Objectives.*

Location	Number of values complying with objective	Maximum Level (mg•L⁻¹)
Devon Bridge	12/12	0.014
E. L. Smith WTP	12/12	0.022
Rossdale WTP	35/36	0.090
50th Street Footbridge	34/36	0.078
Rundle Park Footbridge	35/36	0.112
Beverly Bridge	35/36	0.084
Clover Bar	36/36	0.024
Fort Saskatchewan Bridge	28/30	0.104
Sturgeon-NSR confluence	33/33	0.050
Vinca Bridge	22/22	0.010
Pakan Bridge	28/28	0.010
Total	310/317	

*Objective for lead is 0.05 mg•L⁻¹.

public drinking waters. For the former, a limit of 0.03 $mg.L^{-1}$ has been proposed for lead (Environmental Studies Board 1973), whereas a maximum concentration of 0.05 $mg.L^{-1}$ is usually set for drinking water (Alberta Environment 1977, Department of National Health and Welfare 1979).

9.3 Impacts: Metals

Sixteen metals were analyzed for in this study. With the possible exception of lead, there was no evidence of impact from these on the aquatic environment in the NSR between Devon and Pakan. Although lead levels occasionally exceeded ASWQO, persistent elevated levels were not measured and differences in lead levels between Devon and Pakan were not significant. There is no known point source for lead; instead, the main source is probably surface runoff, which enters the river through storm sewers. Such a diffuse source is difficult to assess or contain.

The fate of lead entering the NSR in the vicinity of Edmonton is not known. The possibility of accumulation in sediments or bioaccumulation in aquatic organisms must be considered, although there is no evidence for such accumulation at the present time.

In general, the levels of metals found in the NSR were low enough that their presence in the river downstream of Edmonton cannot be considered to impair the quality of water for normal domestic or industrial use.

9.4 Sediment

The results of the sediment analyses for the metals are given in Table 9.8. Since there are no quality standards for the sediment component, comparable values for the Red Deer River and the Drywood Creek are shown. Most values for the three streams are very similar.

TABLE 9.8 Metals* in North Saskatchewan River Sediments, 5-6 October, 1983, with comparisons to the Red Deer River and Drywood Creek.

	Devon	50th Street		Beverly Bridge		Pakan		Vinca	Red Deer River	Drywood Creek
		L	R	L	R	L	R			
Lead	17	29	20	62	17	19	22	15	10-40	15-30
Copper	21	18	17	27	14	11	20	14	5-25	10-20
Nickel	25	25	26	23	28	26	37	25	20-50	20-25
Arsenic	5	4	6	4	5	4	5	5	5-10	5-6
Cadmium	0.3	0.3	0.2	0.7	0.2	0.2	0.3	0.2	0.2-0.7	0.2-0.4
Mercury	0.08	0.08	0.07	0.12	0.04	0.06	0.06	0.07	0.06-0.18	0.03-0.07
Zinc	77	74	71	109	72	60	80	64	60-110	50-200
Chromium	62	53	55	65	61	47	68	53	20-120	50-70

* All values in $ug \cdot g^{-1}$.

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10.0 ORGANIC COMPOUNDS

The organic compounds found in the North Saskatchewan River (NSR) and its tributaries originate from natural sources and from the agricultural, resource development, and industrial activities within the basin (Figs. 2.1 and 2.2).

Natural organic compounds are associated with or derived from soils, the chemical and biological degradation of plants and animal residues, the weathering of carbonaceous materials (including coal), and the biosynthetic activities of organisms. Such natural organics can be expected to occur in the aquatic environment. For instance, microbial degradation (eg. by bacteria or fungi) of lignin and lignin-like materials contained in vascular plants and their detritus is one of many processes which results in the natural occurrence of certain phenolic materials. Other organics derived from these and other natural sources include tannin, asphaltenes, aliphatic hydrocarbons, humic substances, many polar compounds, and trace amounts of aromatic hydrocarbons.

Natural non-humic substances, which include carbohydrates, proteins, peptides, amino acids, fats, waxes, and low molecular weight organic acids, are attacked relatively readily by microorganisms and usually have a short life span in the environment. In contrast, humic substances, which usually constitute a large fraction of the total organics, are known to be refractory to biological degradation. They are not single molecules, but associations of molecules of microbiological, polyphenolic, and lignin origins that range in molecular weight from a few hundred to several thousand and vary in composition from source to source. The humic compounds in the association are produced by microorganisms or derived from aquatic and terrestrial plants.

In addition to the natural loadings of organic substances into the NSR, there are anthropogenic inputs of natural and synthetic organic compounds associated with domestic, urban, agricultural, resource-development, and industrial activities within the basin.

With regard to organic compounds in the environment, volatilization and long-range transport may occur during release, storage in lagoons, and transport by the streams and rivers. The compounds that remain in the aquatic environment in suspension, emulsion, or solution can be partitioned into the aqueous and sediment phases where they may undergo biotic and abiotic transformation and/or degradation. In view of the very complex nature of organic substances in the environment, comparatively few data were collected during this study. Consequently, the transport, transformations, and ultimate fate of the organic constituents in the NSR have not been resolved, nor have the causes of specific event problems (e.g., tainting, taste, and odor problems). This section of the overall report is intended as an overview assessment of the results from surveys conducted during 1982 and 1983.

Water samples on selected dates in 1982 were taken at various locations between E. L. Smith Water Treatment Plant and Pakan Bridge. On one date in 1983, eleven transect sediment samples and six transect-composite water samples were collected from locations between and including Devon and Pakan Bridge. These 1983 samples were analyzed for organic pesticides and scanned for PCBs and U.S. EPA priority pollutants. A summary of the sampling dates and analyses performed for organic materials is given in Tables 4.4 and 4.5.

10.1 Results and Discussion - Organic Compounds

10.1.1 Pesticides, Herbicides, and PCBs

Analyses of NSR water samples collected during the open-water season of 1982 and on 5 and 6 October 1983, and of sediment samples collected on 5 and 6 October 1983 revealed no detectable levels of chlorinated pesticides, chlorinated herbicides, organophosphorus or organonitrogen compounds, or PCBs. Analysis in each of these groups involved scans for several specific chemical compounds.

Organochlorine residues such as polychlorinated biphenyls (PCBs) are considered deleterious to aquatic systems because the parent compounds and their metabolites persist in the environment, accumulate in the biota (especially in lipids), and are known mutagens and suspected carcinogens.

10.1.2 Phenolic Materials

Phenolic materials as a group were analyzed as one of the standard variables. The analytical method (NAQUADAT Code 06532L) used is the 4-amino-antipyrene colorimetric method which is accurate for determining the quantity of phenol but not the quantity of all phenolic compounds (e.g., parasubstituted alkyl, aryl, nitro, benzyl, nitroso, and aldehyde forms). Consequently, the results from the colorimetric method are conservative estimates of the amounts present in the samples.

Overall, the analysis of samples collected along the NSR for phenolic materials on most sampling dates in 1982 and some in 1983 produced very low concentrations, frequently equal to or less than the analytical detection limit of 0.002 $mg \cdot L^{-1}$ (Figure 10.1). Detectable concentrations ranging between 0.002 and 0.005 $mg \cdot L^{-1}$ were common during the 1983 open-water seasons. Values greater than 0.005 $mg \cdot L^{-1}$ occurred in the tributary streams, but only rarely (11 times in 2 years) at a few locations in the mainstem NSR (Tables 10.1 and 10.2).

Information on the phenolic materials concentrations in the NSR in the Rocky Mountain and the foothills regions is based on the analysis of 12 samples collected at Rocky Mountain House and at Drayton Valley between 16 June 1983 and 1 February 1984. The concentration reported for each of the 12 samples was less than 0.002 $mg \cdot L^{-1}$.

Further downstream at Devon between 19 May 1982 and 29 February 1984, concentrations in 19 of 24 samples were equal to or less than 0.002 $mg \cdot L^{-1}$, three samples had values of 0.003 $mg \cdot L^{-1}$, and only two samples exceeded 0.005 $mg \cdot L^{-1}$: 14 June 1983 (0.009 $mg \cdot L^{-1}$) and

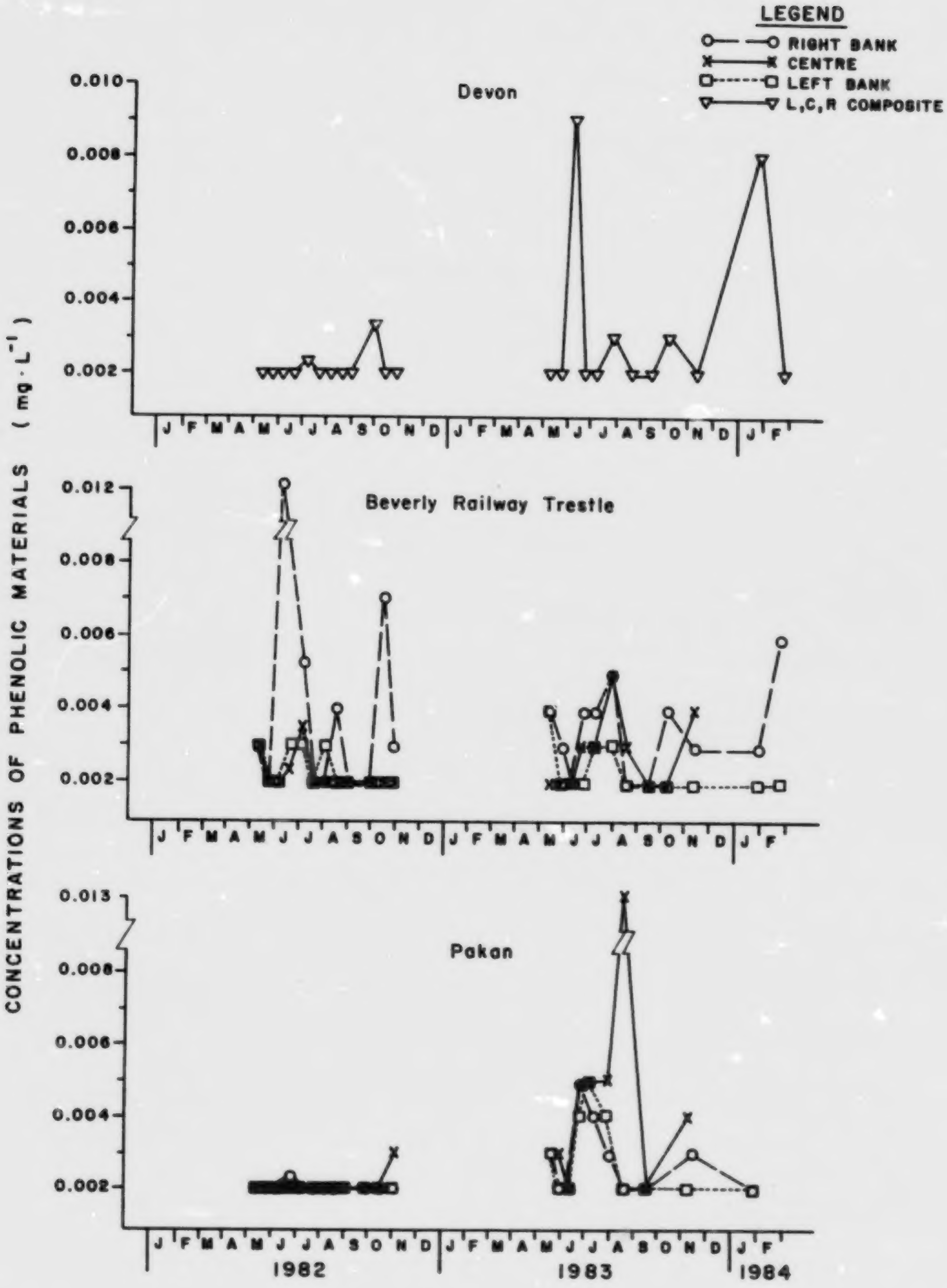

Fig. 10.1 **Variations in the concentrations of phenolic materials in water samples collected at three locations along the North Saskatchewan River .**

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TABLE 10.1 Phenolic materials concentrations (mg.L^{-1}) and estimated loadings (kg.d^{-1}) from tributaries for sampling dates in 1983.

	Whitemud Creek		Millcreek	Fulton Creek	Gold Bar Creek	Redwater River		Sturgeon River		Beaverhill Creek	
Sampling Dates in 1983	Conc.	Loading	Conc.	Conc.	Conc.	Conc.	Loading	Conc.	Loading	Conc.	Loading
17 - 18 May	0.013	----	0.023	----	0.012	----	----	----	----	----	----
26 May - 2 June	0.013	0.110	----	----	----	0.009	0.076	0.007	1.421	----	----
16 June	----	----	----	----	----	0.003	0.102	0.008	0.541	----	----
28 - 29 June	0.009	11.880	0.015	0.049	ND	0.020	14.040	0.008	8.325	0.020	23.010
13 - 14 July	0.017	17.400	0.022	0.061	0.012	0.014	4.500	0.012	11.070	0.015	4.061
3 - 4 August	0.024	2.640	0.035	0.093	0.011	0.015	1.015	0.011	4.653	0.017	0.719
23 - 24 August	0.009	----	----	0.150	0.013	0.008	0.068	0.008	1.150	0.005	----
20 - 21 September	0.005	----	----	----	0.027	0.009	0.076	0.008	0.338	0.003	----
12 October	0.124	----	----	----	0.015	----	----	----	----	----	----
15 - 17 November	0.011	----	----	----	----	0.011	----	0.008	----	0.012	----

ND = Not Detectable
---- = No Data

TABLE 10.2 Occurrences along the North Saskatchewan River of phenolic materials concentrations greater than 0.005 $mg \cdot L^{-1}$.

Sampling Date	DEVON Composite	ROSSDALE Right	ROSSDALE Centre	RUNDLE FOOTBRIDGE Right	BEVERLY RAILWAY TRESTLE Right	BEAVERHILLS CREEK CONFLUENCE Left	PAKAN Centre
1982							
15 June					0.012		
29 June		0.007	0.009				
13 July				0.008			
19 October					0.007		
1983							
14 June	0.009						
29 June						0.006	
14 July						0.006	
24 August							0.013
1984							
1 February	0.008						
29 February					0.006		

1 February 1984 (0.008 $mg \cdot L^{-1}$). The relative proportions of the numbers of very low, moderate (between 0.002 and 0.005 $mg \cdot L^{-1}$), and high (greater than 0.005 $mg \cdot L^{-1}$) values were found to persist in transect samples collected at all downstream stations except the Beverly Bridge (right-bank site), where there were fewer low values and an increase in the number of occurrences of phenolic materials concentrations greater than 0.003 $mg \cdot L^{-1}$.

A number of factors can cause the transformation or removal of various organic constituents as they travel from points of release, through major drains or lagoons, and into receiving waters. Examples of these factors are photolysis, adsorption, aeration (which aids volatilization and oxidation), metabolic degradation, and microbial degradation, if suitable organisms are present. Furthermore, dilution or masking due to variations in effluent quantity and quality would increase the chance of not detecting phenolic materials in a large river, such as the NSR, on any two successive sampling dates.

The presence of phenolic materials at concentrations greater than 0.002 $mg \cdot L^{-1}$ has been observed in other Alberta rivers. However, detectable levels generally occur in summer and are believed to derive from natural seasonal processes such as those described previously. The presence of high levels of phenolic materials in the NSR water samples collected at Devon on 1 February 1984 and within and below Edmonton reflects inputs from tributary streams (Table 10.1) and point-source discharges (Table 10.3) entering the NSR.

TABLE 10.3 Phenolic materials concentrations ($mg.L^{-1}$) and estimated mean daily loadings ($kg.d^{-1}$) from municipal sewage discharges, NSR, 1983.

Sampling Dates in 1983	Devon Sewage Treatment Plant		Gold Bar Wastewater Treatment Plant		Bremner Sewage Lagoons		Ft. Saskatchewan Sewage Lagoons		St. Albert Sewage Lagoons		Total Loading from Municipal Sewage Plants
	Conc.	Loading	Conc.	Loading	Conc.	Loading	Conc.	Loading	Conc.	Loading	
17 - 18 May	0.012	0.018	0.015	3.359	-----	-----	0.196	0.590	0.206	2.262	6.229
31 May - 2 June	0.011	0.014	0.017	4.042	-----	-----	0.186	0.563	0.171	2.202	6.821
14 - 16 June	0.011	0.017	0.012	2.826	0.454	10.360	0.189	0.588	0.047	0.520	14.311
28 - 29 June	0.007	0.015	0.010	3.505	0.379	10.390	0.202	0.696	0.029	0.430	15.036
13 - 14 July	0.007	0.013	0.011	3.452	0.306	12.280	0.137	0.464	-----	-----	16.209
3 - 4 August	0.012	0.021	0.011	3.037	0.033	3.906	0.126	0.373	0.018	0.207	7.541
23 - 24 August	0.007	0.011	0.010	2.470	-----	-----	0.119	0.389	0.014	0.159	3.029
20 - 21 September	0.007	0.011	0.052	12.150	0.028	0.543	0.137	0.329	0.014	0.150	13.183
12 - 13 October	0.011	0.017	0.013	2.872	-----	-----	-----	-----	-----	-----	-----
15 - 16 November	0.009	0.014	0.012	2.853	-----	-----	-----	-----	-----	-----	-----

A selection of longitudinal plots of phenolic materials concentrations in transect samples collected during the summer and autumn of 1982 and summer of 1983 is given in Figures 10.2 and 10.3. These plots demonstrate the general tendency for levels to be higher in the right-bank samples collected in the vicinity of Edmonton than the corresponding left-bank samples. This is due to the combined effects of many small inputs of phenolic compounds from municipal and industrial sources.

10.1.3 Other Organic Compounds

10.1.3.1 Water Phase

Water samples collected in the October 1983 survey were analyzed for PCBs, acid and base/neutral fractions, and purgeable priority pollutants. The purgeable group consisted of benzene and 23 compounds from the general categories of haloalkanes, haloalkenes, alkylbenzenes, and mono- and dichloro-benzenes. For this group, there were a few single measurements above the detection level: toluene and metaxylene (0.0002 mg.L^{1} at Devon), tetrachloroethylene (0.0001 mg.L^{-1} at Beverly Bridge), xylene (0.0001 mg.L^{-1} at Pakan). Most of the other purgeable priority pollutants were detected in the water samples of the October 1983 survey, but all were at levels below 0.0001 mg•L^{-1}, except those noted above.

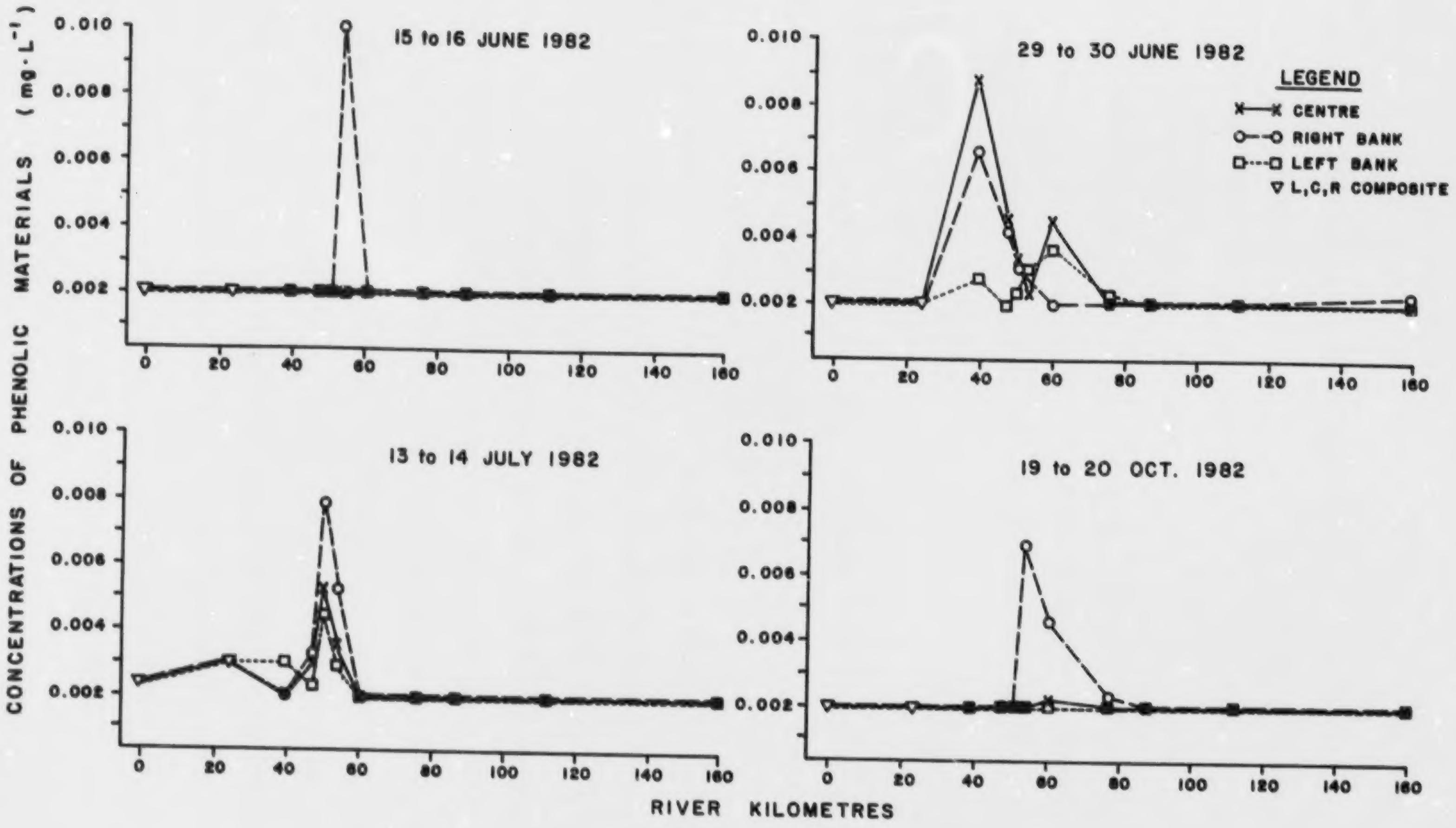

Fig. 10.2 Longitudinal variations in phenolic materials concentrations in the North Saskatchewan River for selected dates in 1982.

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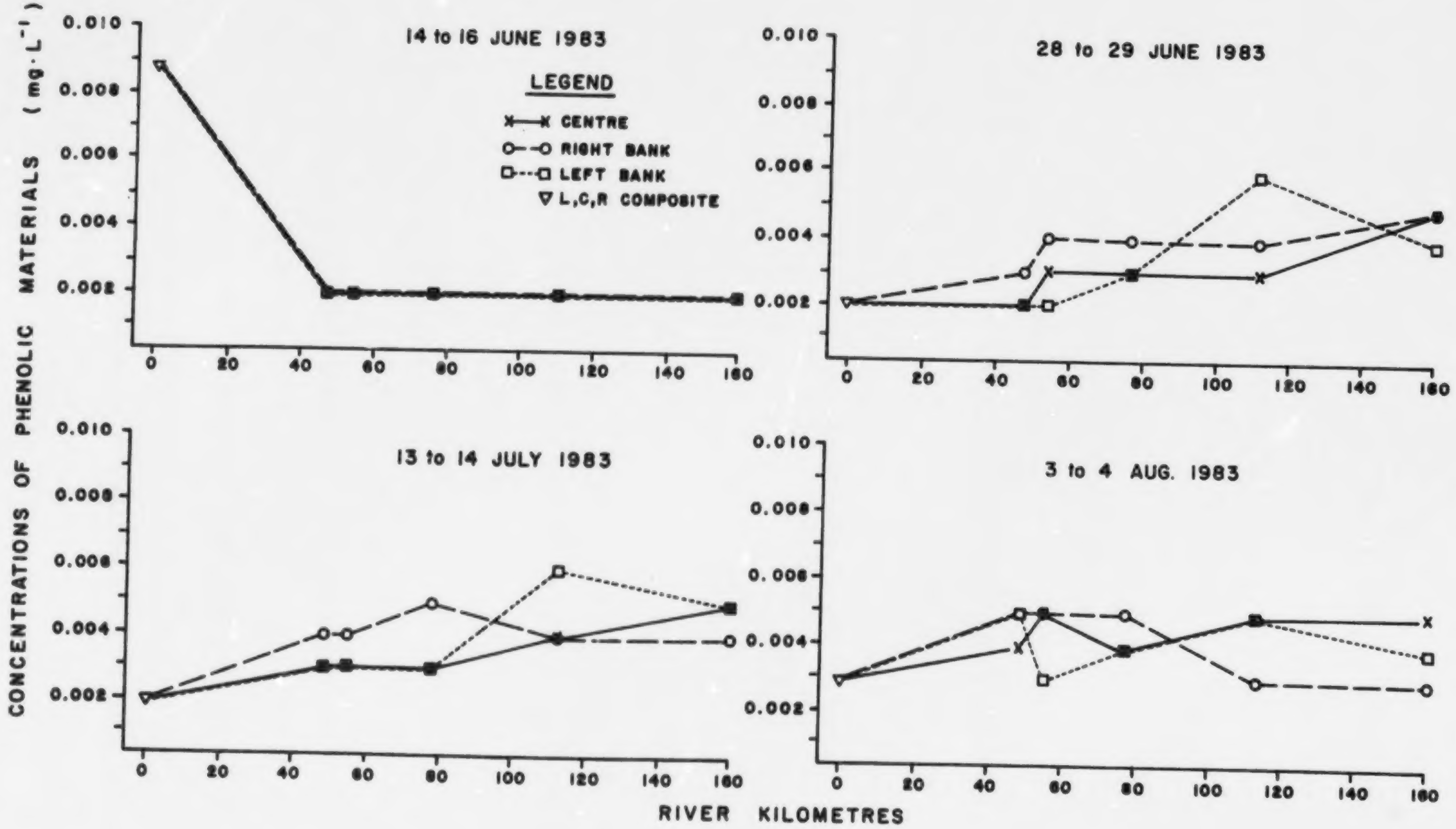

Fig. 10.3 Longitudinal variations in phenolic materials concentrations in the North Saskatchewan River for selected dates in 1983.

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Analyses were carried out on the watr samples for sixty-one compounds comprising the acid and base/neutral fractions. There were two positive detections in each of the water samples from the Devon and Beverly Bridge locations. The Devon sample contained bis (2-ethylhexyl)-phthalate at a concentration between 0.0005 and 0.001 $mg \cdot L^{-1}$, and di-n-butylphthalate at a concentration between 0.0001 and 0.0005 $mg \cdot L^{-1}$. The same two compounds were present in the Beverly Bridge water samples at concentrations between 0.00001 and 0.0001 $mg \cdot L^{-1}$. The other 59 compounds from the acid and base/neutral fractions were not detected.

10.1.3.1 Sediment Phase

The acid and base/neutral fractions were also analyzed for in 11 transect sediment samples. The results summarized in Table 10.4 show that certain organic compounds (e.g., benzothiazole, pyrene, and hexadecanoic acid) occurred at some locations. Saturated straight-chain aliphatic hydrocarbons (C_{14} to C_{23}), in the concentration range 0.01 to 0.1 $mg \cdot g^{-1}$, and similar amounts (0.01 to 0.1 $mg \cdot g^{-1}$) of phthalic acid esters [e.g., bis (2-ethylhexyl) -phthalate, di-n-butylphthalate, and diethylphthalate] occurred at almost all locations. Branched aliphatic hydrocarbons (molecular weight 150 to 450 Daltons) were observed at various concentration ranges (10 to 470 $mg \cdot g^{-1}$); the higher values occurred at Beverly Bridge (left-bank site), Fort Saskatchewan (right-bank site) and Vinca (right-bank site).

TABLE 10.4 Concentrations of organic constituents in the North Saskatchewan River sediments, 5 - 6 October 1983.

CHEMICALS	OBSERVED CONCENTRATION RANGE $mg \cdot g^{-1}$ dry wt.	DEVON	50 STREET BRIDGE		BEVERLY BRIDGE		FT. SASKATCHEWAN		VINCA		PAKAH
			RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	RIGHT	LEFT	
RIGHT LEFT											
Elemental molecular sulphur (S_6,S_7,and/or S_8)	0.01 - 10.0	X	X	X	X			X	X		
Saturated straight chain aliphatic hydrocarbons (C_{14} to C_{23})	0.01 - 0.1	X	X	X	X	X	X		X		X
Saturated branched aliphatic hydrocarbons (M.W. 150 to 450)	10 - 45	X	X		X					X	X
	110 - 200			X				X			
	220 - 300						X		X		
	420 - 470					X					
Bis (2-ethylhexyl)	0.01 - 0.1		X	X	X		X		X	X	X
	0.1 - 0.5							X			
Di-n-butylphthalate	0.01 - 0.1	X	X		X		X			X	
Diethylphthalate	0.01 - 0.1				X						
Benzothiazole	0.01 - 0.1	X	X							X	
Pyrene	0.01 - 0.1		X				X				
Methyl hydroxy substitued polycyclic (M.W. 234)	0.1 - 0.5		X								
Hexadecanoic acid	0.01 - 0.1			X						X	
Methoxy disulphide substituted organic (M.W. 266)	0.01 - 0.1							X			

Analysis for elemental molecular sulphur (S_6, S_7, and/or S_8) was also carried out on the acid and base/neutral fractions, and sulphur was present in the concentration range 0.01 to 10.0 $mg \cdot g^{-1}$ in seven of eleven samples.

Sediments in the river concentrate some of the organic compounds. Whether an organic compound concentrates or not depends upon a number of factors, which may include the composition of the bottom sediment, sorption, biodegradation, bioaccumulation, and other factors.

10.2 Surface Water Quality Objectives

The Alberta Surface Water Quality Objectives (ASWQO) for pesticides, herbicides, and PCBs are not set out in absolute concentrations, whereas most other constituents covered in this report are. Instead, "to provide reasonably safe concentrations of these materials in receiving waters, an application shall not exceed 1/100 of the 48-hour Tl_m" (p. 6, Alberta Environment 1977). No detectable levels of these substances were found in the NSR in the course of this investigation. This does not prove that exceedences never occur, but it does indicate that exceedences are likely to be very uncommon.

An ASWQO criterion of 0.005 $mg \cdot L^{-1}$ has been set for "phenolics" (i.e. total phenolics), a designation which includes a great many different but related compounds. The level of total phenolics measured in NSR samples in the course of this study usually complied with the ASWQO. Because analyses were for total phenolics rather than for specific phenolic compounds, it is unwise to discuss criteria for domestic water supplies, criteria for the protection of aquatic life, potential taste and odor (organoleptic) properties, or other deleterious qualities which might be due to the presence of the low concentrations of specific phenolic compounds in the NSR. Even minute concentrations (i.e. levels well below the stated ASWQO) of certain phenolic compounds can impart a taste to water, an effect which may be intensified by chlorination.

Concentrations for purgeable priority pollutants and base/neutral fractions are not specified in the ASWQO. Most of these compounds were detected at or very little above trace levels; none was present at concentrations greater than 0.0002 $mg \cdot L^{-1}$, and most concentrations were less than 0.0001 $mg \cdot L^{-1}$.

No standards have yet been set or proposed for organics in river sediments.

10.3 Impacts

The presence of pesticides, herbicides, and PCBs at the levels detected in the NSR (i.e. below detection limits) is no cause for concern, even though some of these substances are known mutagens or suspected carcinogens. However, there is need for vigilance, because of the possible but unknown cumulative effects of even low concentrations of different organic compounds and because of the tendency of some to accumulate in the biota or in the sediments.

At the measured levels for phenolics in the NSR, impacts on the river biota are likely to be slight. Impacts on the quality of water intended for domestic use are likely to be mainly aesthetic (especially taste), although detailed analyses for specific compounds would be warranted before even low concentrations are dismissed as being insignificant.

The toxicity of phenolic compounds varies with the type, position, and number of substitutions on the parent molecule. Furthermore, it is widely believed that chlorinated phenolic compounds pose greater environmental hazards than phenol or other non-chlorinated phenolic compounds. Therefore, a proper assessment of the potential toxic effects of the phenolic compounds discharged into the NSR would require information on river mixing along certain sections of the river, constituent loading and dilution coefficients along these sections, and factors and conditions influencing the toxicities of phenolic compounds to various test organisms (Buikema, Jr., et al. 1979). The effects of many chemical toxicants, especially at low concentrations, are difficult to quantify and even more difficult to predict. Long-term exposure of organisms to specific toxicants at low concentrations may result in acclimation or increased resistance to short-term exposure to similar toxicants at higher concentrations.

The presence of acid and base/neutral fractions and purgeable priority pollutants at or near the detection limit suggests that at present these compounds are not a threat to NSR water users downstream of Edmonton. However, the known presence of these compounds in the aquatic environment and a lack of understanding of the consequences of this presence reinforces the need to minimize the quantities of these compounds which enter Alberta rivers.

As indicated earlier, little is known about potential environmental dangers due to the presence of acid and base/neutral fractions and purgeable priority pollutants at low concentrations over extended time periods. Therefore, comments must be reserved regarding environmental or health effects from trace amounts of organic substances in NSR bottom sediments.

11.0 NUTRIENTS: PHOSPHORUS AND NITROGEN

Elements and their compounds that are required in relatively large amounts for plant growth are called macronutrients, or simply "nutrients". The two nutrient groups most commonly limiting plant growth or production are compounds or "forms" of phosphorus and nitrogen. Consequently, increases in the concentrations of these two nutrient groups are the usual causes of eutrophication or increased fertility of rivers and lakes.

Eutrophication is the elevation of nutrient levels from all sources, both natural and cultural. Cultural eutrophication or "cultural enrichment" is the elevation of nutrient levels through pollution resulting from human activities (Odum 1971). Such enrichment, particularly by compounds of phosphorus and nitrogen, stimulates plant growth beyond natural levels; such excessive growth can be the cause of low oxygen levels (especially in summer at night or during winter), high turbidity, some taste and odor problems, and nuisance blooms of certain algal species.

The phosphorus in surface waters has both natural and anthropogenic sources, and it occurs in a number of forms. It occurs naturally from the weathering and leaching of apatite and igneous rocks, and from the decomposition of naturally occurring organic matter. Anthropogenic sources include effluents from municipal sewage treatment plants and industries, and surface drainage from agricultural and urban lands. For the 1982-1983 study, phosphorus was measured as total phosphorus (TP), which includes all forms of phosphorus present in the water, both organic and inorganic, dissolved and particulate.

Two techniques were used in total phosphorus analysis during this study. In 1982, analyses were based on Standard Methods (American Public Health Association _et al_. 1980), whereas in 1983, analyses were based on a semi-automated procedure (Crowther _et al_. 1978). In 1982, samples from selected NSR sites were split and analyzed separately to compare the two analytical techniques; results were tested statistically and showed no significant differences between techniques ($P < 0.05$, $N = 14$). For additional details on sampling and analysis for phosphorus, refer to general methods (Section 5.0).

Nitrogen occurs in several organic and inorganic forms in the aquatic environment. Natural sources include the fixation of atmospheric elemental nitrogen by certain bacteria and blue-green algae, precipitation, surface drainage, and groundwater. The main anthropogenic sources include effluents from municipal sewage treatment plants and industries, and surface drainage from agricultural and urban lands.

Analyses were conducted for four nitrogen forms during this study, grouped as follows:

Total Kjeldahl Nitrogen (TKN)
Ammonia Nitrogen (NH_3-N)
Nitrate + Nitrite Nitrogen ($NO_3 + NO_2 - N$)
Nitrite Nitrogen (NO_2-N)

The TKN analysis includes both organic and ammonia nitrogen. The organic component can be obtained by subtracting (NH_3-N) from (TKN). Ammonia nitrogen (NH_3-N) is the total of all nitrogen in the forms of ammonium hydroxide (NH_4OH), ammonium ion (NH_4^+) and ammonia (NH_3). An estimate of total nitrogen (TN) is obtained by adding (TKN) and (NO_3 + NO_2 -N). Analytical techniques used for these variables were less sensitive in 1982 than in 1983, and concentrations at upstream sites in 1982 were often below the detection limit of the technique employed. Therefore, nitrogen results are given for 1983 only. For additional details on sampling and analysis for nitrogen, refer to general methods (Section 5.0).

For reasons explained earlier in this report (Section 5.3), median values rather than mean values were used for comparing phosphorus and nitrogen data from different sites.

11.1 Results and Discussion: Total Phosphorus

Median values were determined for all TP data collected over the two-year study period for each of left-bank, centre-channel, and right-bank sites at each of the NSR locations except Devon and E.L.Smith, where composites of left-bank, right-bank, and centre-channel samples had been analyzed. Results are summarized in Figure 11.1.

Total phosphorus concentrations in the NSR during the study period varied spatially and seasonally. Spatial differences were evident between upstream and downstream locations and between

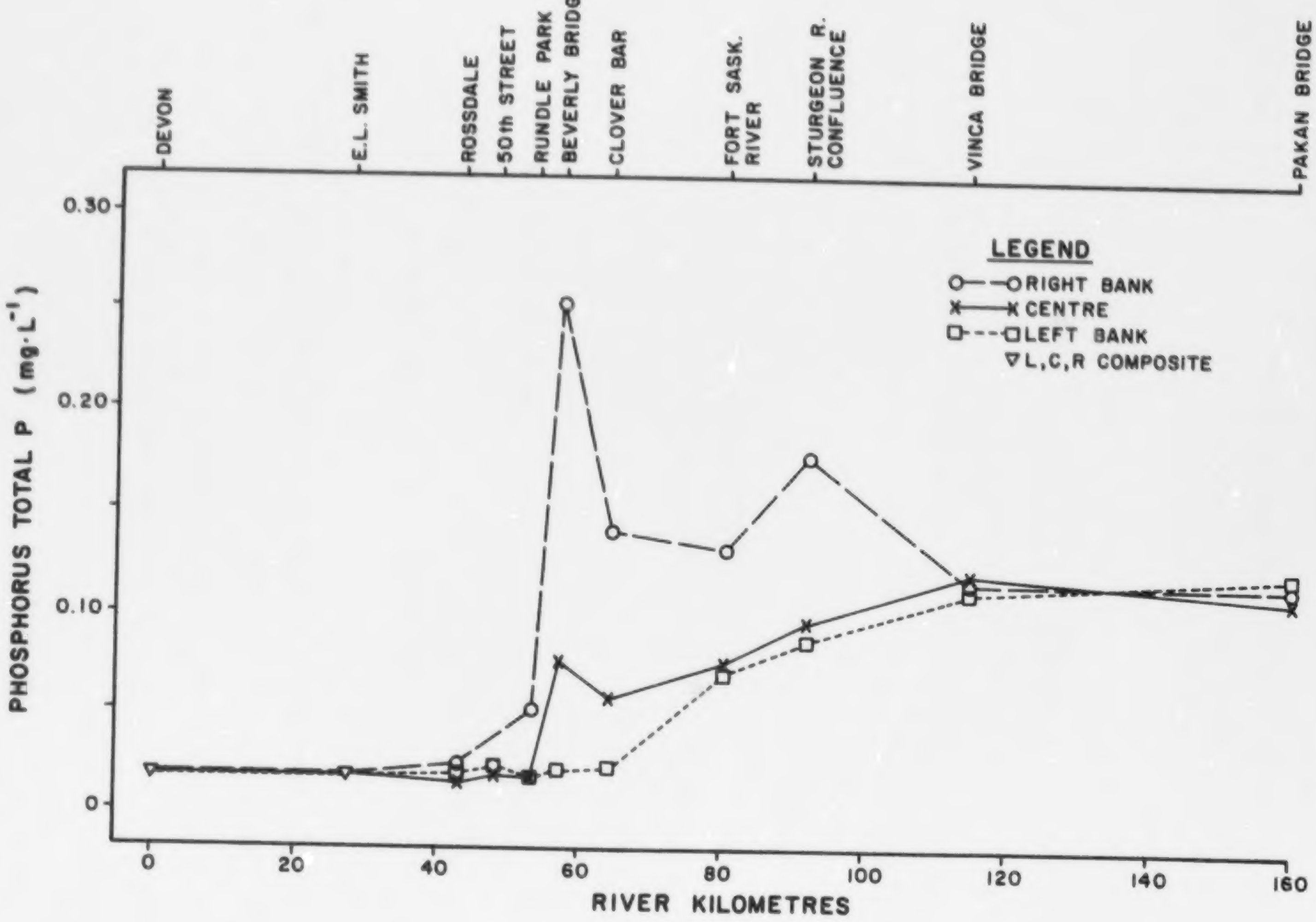

Fig. 11.1 Median total phosphorus values, NSR, 1982-1983.

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left-bank and right-bank sites; seasonal variability in TP concentrations was apparent at certain sites, reflecting periods of high and low flow.

Median TP values for the four Devon to 50th Street locations ranged from 0.016 to 0.024 $mg \cdot L^{-1}$. These levels were comparatively low and the range indicates considerable site-to-site stability. From Rundle Footbridge to Sturgeon River, right-bank median values ranged from 0.051 to 0.254 $mg \cdot L^{-1}$, showing higher concentrations and greater longitudinal variability than corresponding left-bank (0.018 to 0.083 $mg \cdot L^{-1}$) or centre-channel (0.018 to 0.099 $mg \cdot L^{-1}$) median values. Median TP values for left-bank, centre-channel, and right-bank sites ranged from 0.112 to 0.122 $mg \cdot L^{-1}$ for Vinca and from 0.110 to 0.120 $mg \cdot L^{-1}$ for Pakan. There were significant differences between left-bank and right-bank values for Vinca, but not for Pakan ($P < 0.05$, $N = 20$). Median TP values are much higher downstream than upstream in the study section of the NSR, but site-to-site stability in TP values at Pakan is comparable to that of the Devon and E.L. Smith locations.

Figure 11.2 summarizes longitudinal differences between median TP values for left-bank and right-bank sites during periods of high flow (May to July) and low flow (August to March), based on the following summary of river discharges for all sampling dates from May 1982 to March 1984:

	May to July	August to March
Median ($m^3 \cdot s^{-1}$)	286	121
Range ($m^3 \cdot s^{-1}$)	(229 - 726)	(83 - 213)

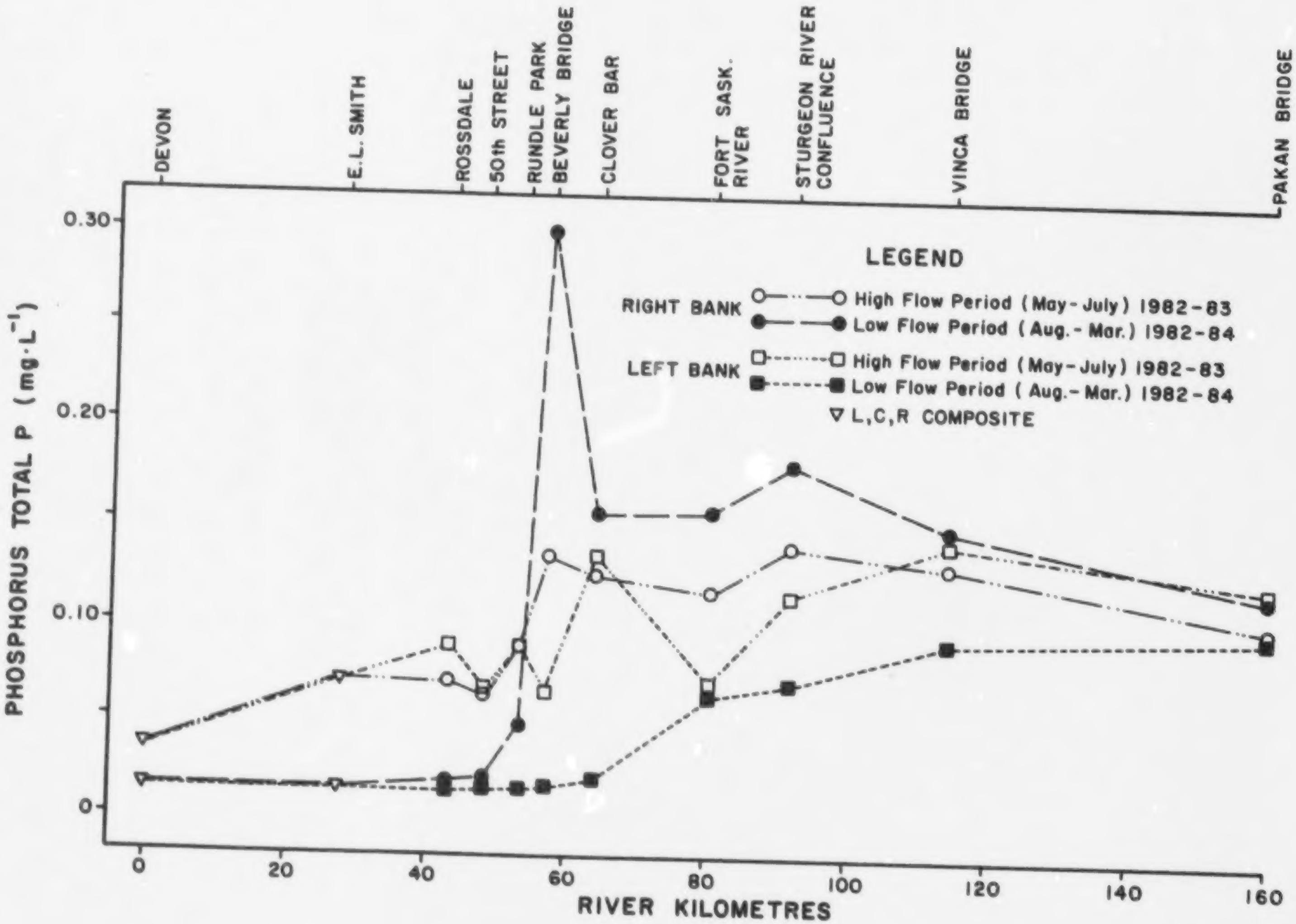

Fig. 11.2 Total phosphorus, NSR, 1982-1983; median left bank and right bank values for the study period.

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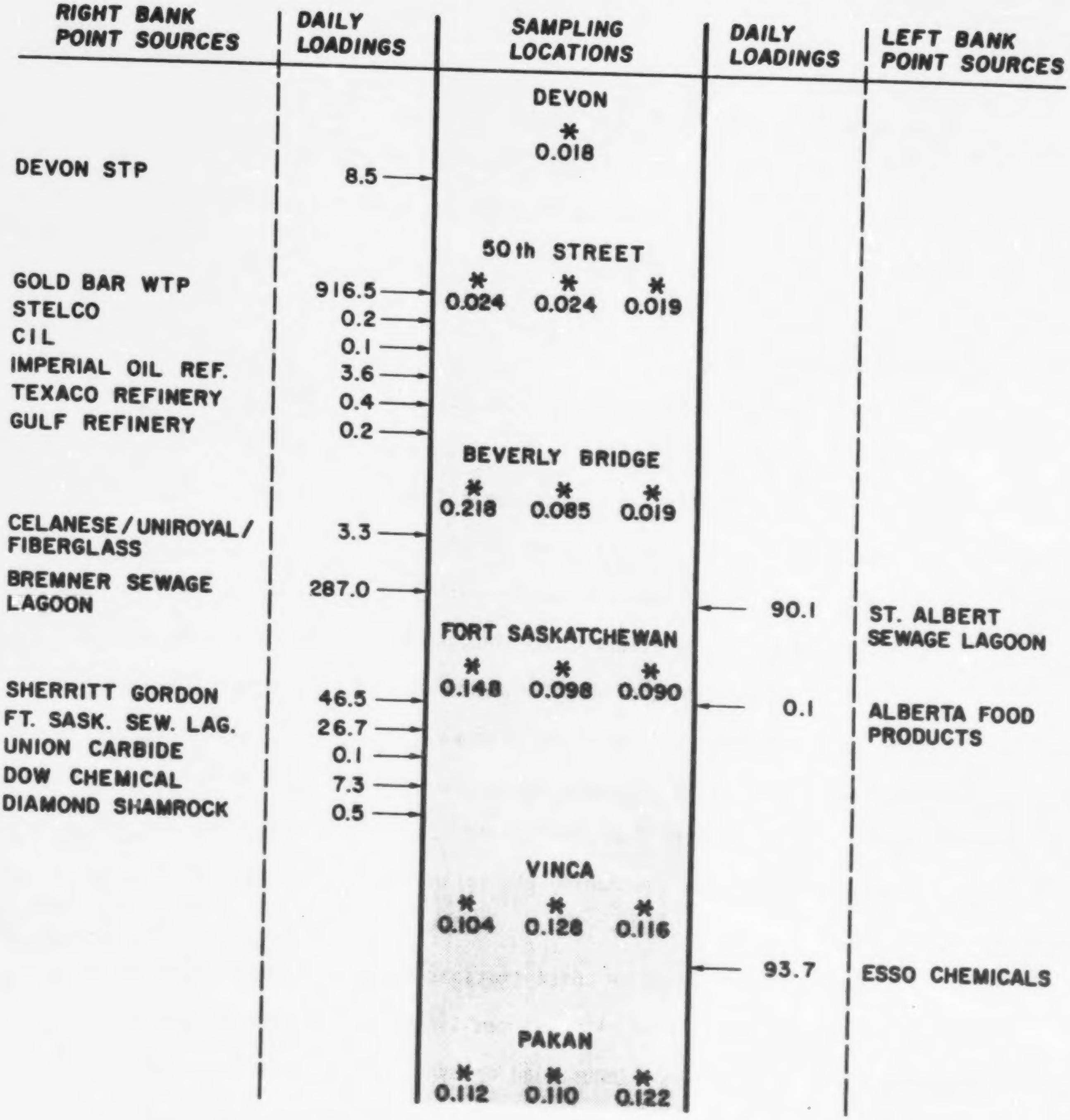
From Devon to Rundle Footbridge, bank-to-bank differences in TP were usually small and the highest concentrations usually occurred during the high-flow period. Locations downstream of Rundle Footbridge showed greater bank-to-bank differences, but these differences tended to diminish in downstream direction.

The spatial variability in median TP values (bank-to-bank and upstream-downstream) in the NSR is attributable to point-source discharges high in TP entering the river. Figure 11.3 summarizes the estimates of loading to each bank of the NSR from continuous-effluent sources: municipal sewage treatment plants (M) and industries (I). Loads were calculated using the same methods as for major ions (Section 8.1).

Approximately 87% of all continuous point-source phosphorus discharge enters the NSR on the right bank between 50th Street Footbridge and Vinca. This is consistent with the higher concentrations measured in right-bank samples in this part of the study section of the NSR. The more gradual increase in TP concentrations in centre-channel samples and the absence of an increase in TP concentrations in left-bank samples until Fort Saskatchewan are probably a reflection of both the slow lateral mixing characteristics of the NSR and the smaller loads from left-bank point sources (Fig. 11.3). The small differences in the median TP concentrations among left-bank, right-bank, and centre-channel sites at Vinca and Pakan and the absence of major point-source discharges between these two locations suggests that the river is mixed at the downstream locations.


RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
0.018
DEVON STP
8.5
50th STREET
GOLD BAR WTP
916.5
0.024 0.024 0.019
STELCO
0.2
CIL
0.1
IMPERIAL OIL REF.
3.6
TEXACO REFINERY
0.4
GULF REFINERY
0.2
BEVERLY BRIDGE
0.218 0.085 0.019
CELANESE/UNIROYAL/FIBERGLASS
3.3
BREMNER SEWAGE LAGOON
287.0
90.1
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
0.148 0.098 0.090
SHERRITT GORDON
46.5
0.1
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
26.7
UNION CARBIDE
0.1
DOW CHEMICAL
7.3
DIAMOND SHAMROCK
0.5
VINCA
0.104 0.128 0.116
93.7
ESSO CHEMICALS
PAKAN
0.112 0.110 0.122

TOTAL INDUSTRIAL LOAD	=	156.0
TOTAL MUNICIPAL LOAD	=	1328.8
TOTAL DAILY LOAD	=	1484.8

Fig. 11.3 Diagrammatic representation of 1983-84 median T. Phosphorus concentrations (mg·L⁻¹) and estimated municipal and industrial point source loadings (kg·d⁻¹)

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Loadings from intermittent point sources, such as tributary streams and storm sewers, were not included in the above summary, even though contributions from these sources are important during the period of spring runoff and heavy rains. Table 11.1 shows that during late June and early July, 1983, tributaries were a major source of TP loading to the NSR.

A mass-balance estimate suggests that more phosphorus entered the study section of the NSR than could be accounted for by the differences between the loads at Devon and Pakan. Because phosphorus is considered to be a non-conservative element, this deficit implies that there was some phosphorus uptake within this section of the NSR. Phosphorus taken up by potamo-phytoplankton would be included in the estimate of TP at Pakan; however, phosphorus taken up by epilithic and other attached algae and macrophytes would not. Much of the phosphorus taken up by attached plants during the period of active growth would be flushed from the system as they die off during the winter or are scoured out during the spring and early-summer high-flow periods.

Seasonal changes in TP concentrations appeared to be related to variations in river flow. At upstream locations, which were not influenced by continuous industrial or municipal point-source inputs (Devon to 50th Street), TP concentrations were consistently higher during periods of high flow (Fig. 11.2). The naturally high load of suspended sediments during this period (see Section 8.0) may have been the reason for these elevated concentrations. Major nutrient data

TABLE 11.1 Estimated Total Phosphorous and Total Nitrogen Loads (kg·d^{-1})
To North Saskatchewan River from Major Tributary Streams, 1983.

LOCATION:	WHITEMUD		STURGEON		REDWATER		BEAVERHILLS		TOTALS	
DATE	TP	TN	TP	TN	TP	TN	TP	TN	TP	TN
17/05	0.4	2.	18.7	218.	0.4	8.	-	-	19.5	228.
31/05	2.4	9.	14.1	189.	1.1	20.	-	-	17.6	218.
16/06	-	-	8.6	104.	11.1	25.	-	-	19.7	129.
28/06	1078.3	3437.	340.1	2391.	200.8	1248.	352.5	3819.	1971.7	10,895.
13/07	1076.8	3032.	419.1	2119.	151.0	847.	91.2	279.	1738.1	6277.
03/08	38.2	382.	-	1153.	23.5	174.	12.1	97.	73.8	1806.
23/08	-	-	15.4	311.	1.2	10.	-	1.	16.6	322.
21/09	-	-	4.3	108.	1.6	14.	-	2.	5.9	124.
17/11	-	-	-	39.	-	14.	-	1.	-	54.

TP = total phosphorus

TN = total nitrogen

from the Devon station of the Alberta Environment River Water Quality Monitoring Network during 1982-1983 show that higher TP concentrations occurred in association with high suspended sediments, measured as non-filterable residue (NFR):

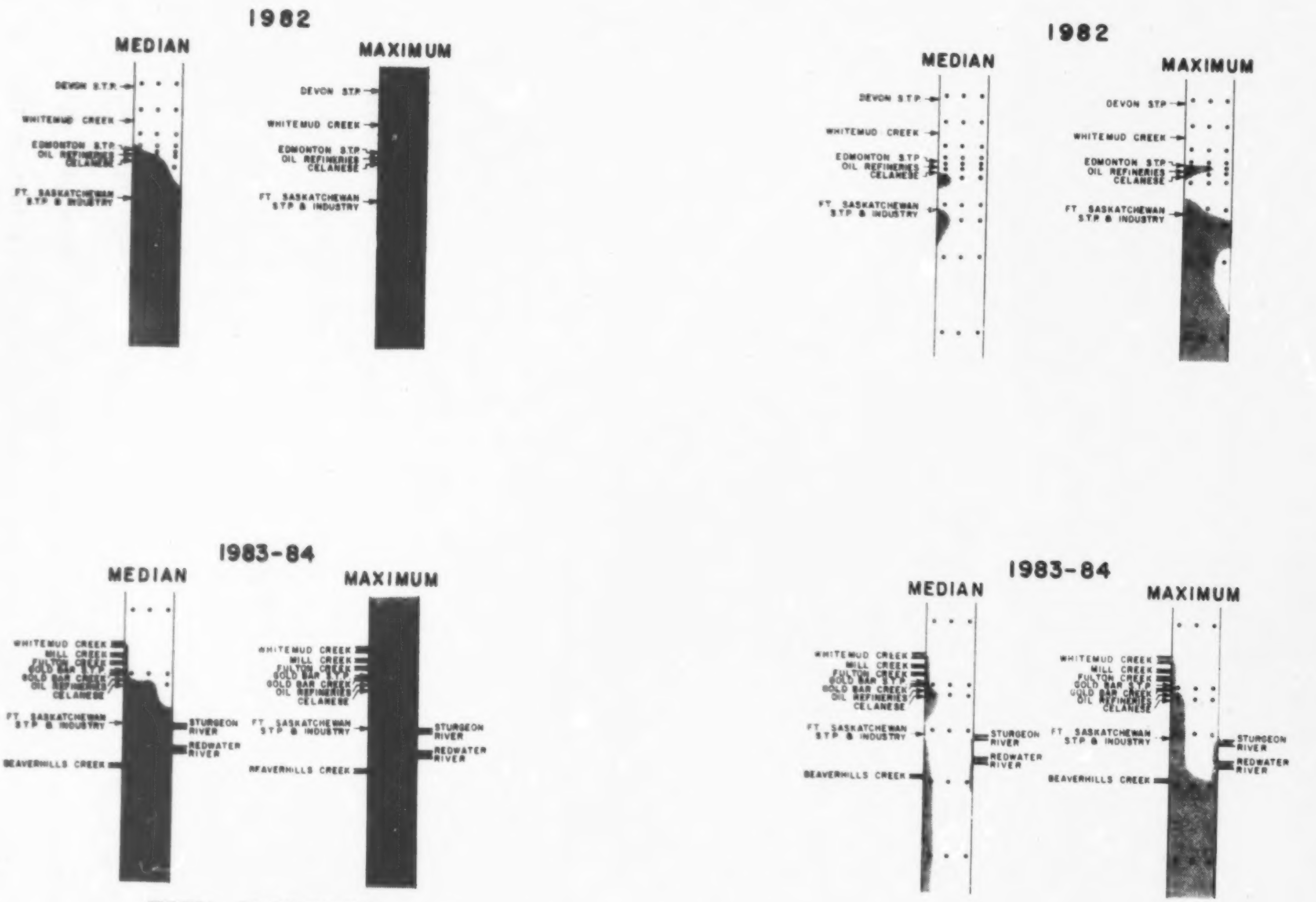
	Total Phosphorus ($mg \cdot L^{-1}$)	Particulate Phosphorus ($mg \cdot L^{-1}$)	Dissolved Phosphorus ($mg \cdot L^{-1}$)	NFR ($mg \cdot L^{-1}$)
HIGH FLOW (May-July)	0.083	0.075	0.008	79.2
LOW FLOW (Aug.-Nov.)	0.016	0.012	0.004	10.3

Most of the measured total phosphorus was in particulate form.

Downstream locations, which received continuous point-source discharges of total phosphorus, showed greater differences in bank-to-bank TP concentrations during low-flow periods (Fig. 11.2). The smaller bank-to-bank differences found during high flow were probably due to dilution from lateral mixing, which was more rapid and thorough during high-flow periods because of greater turbulence, water volumes, and flow velocities at this time. Contributions from tributary streams on the left bank were usually greater during high flow and tended to reduce bank-to-bank differences.

11.2 Surface Water Quality Objectives: Phosphorus

The Alberta Surface Water Quality Objectives (ASWQO) recommend that total phosphorus not exceed 0.05 $mg \cdot L^{-1}$ (Alberta Environment 1977). Figure 11.4 is a diagrammatic representation of


1982
MEDIAN
MAXIMUM
DEVON S.T.P.
WHITEMUD CREEK
EDMONTON S.T.P.
OIL REFINERIES
CELANESE
FT. SASKATCHEWAN S.T.P. & INDUSTRY
1983-84
MEDIAN
MAXIMUM
WHITEMUD CREEK
MILL CREEK
FULTON CREEK
GOLD BAR S.T.P.
GOLD BAR CREEK
OIL REFINERIES
CELANESE
FT. SASKATCHEWAN STP & INDUSTRY
BEAVERHILLS CREEK
STURGEON RIVER
REDWATER RIVER

TOTAL PHOSPHORUS

TOTAL NITROGEN

Fig. 11.4 River reaches in which nutrients exceeded Alberta surface water quality objectives.

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the extent to which median and maximum TP concentrations in the NSR exceeded the 0.05 $mg \cdot L^{-1}$ objectives in 1982 and 1983.

Even though median TP concentrations at the upstream sites did not exceed the ASWQO, about 20% of individual samples in 1983-1984 and about 30% in 1982 had concentrations greater than the objectives. Concentrations greater than the objectives at upstream locations occurred mainly during high-flow conditions because of the naturally high suspended sediment load. Most of the total phosphorus at this time was particulate (see Section 11.1) and probably of apatite origin. Therefore, it was unlikely that most TP was in a form that was biologically available (McNeely et al. 1979).

At downstream sites, the objectives were exceeded in 85% of the samples in 1982, and 95% of the samples in 1983. Many of the sites where TP concentrations exceeded objectives were close to effluent outfalls, where guidelines do not apply (see Section 5.4). At Pakan, however, where mixing is believed to be complete most of the time, objectives were exceeded in 90 to 95% of the samples. Long-term data from the Pakan station of the River Water Quality Monitoring Network indicate that most of the TP at this location was in the dissolved fraction and was likely biologically available.

11.3 Impacts: Phosphorus

The many forms or "species" of phosphorus which occur in surface waters are not commonly toxic to man or aquatic life (McKee and Wolf 1963), but certain forms are known to be key limiting factors in the growth of aquatic plants. When sufficient nitrogen is present in the water, biologically available phosphorus at concentrations near 0.1 $mg \cdot L^{-1}$ may be the cause of nuisance growths of macrophytes, certain algae, or slimes (McNeely et al. 1979).

Although extensive macrophyte growth has not been a problem in past years, the potential for nuisance growths of macrophytes could be realized if current nutrient levels (especially phosphorus) persist in combination with certain other conditions, such as low river flows (contributing to increased water clarity and higher temperatures) and low spring runoff (reducing scouring). These relationships are discussed at greater length in Sections 12.3 and 16.0.

11.4 Results and Discussion: Nitrogen

In general, the spatial distribution of nitrogen forms in the study section of the NSR in 1983-1984 was comparable to that described above for total phosphorus during the same period (Figs. 11.5, 11.6, 11.7). Median concentrations of all three forms (TKN, NH_3-N, and NO_3 + NO_2-N) were lowest at the Devon and 50th Street Footbridge locations. Bank-to-bank differences in all three forms were not significant at the 50th Street Footbridge ($P < 0.05$, $n = 12$). From the Beverly Bridge location through to Vinca, right-bank samples had consistently higher concentrations of all three forms of nitrogen than the corresponding centre-channel or left-bank samples. However, concentrations at centre-channel and left-bank sites increased gradually, reaching highest levels at Vinca or Pakan. Although

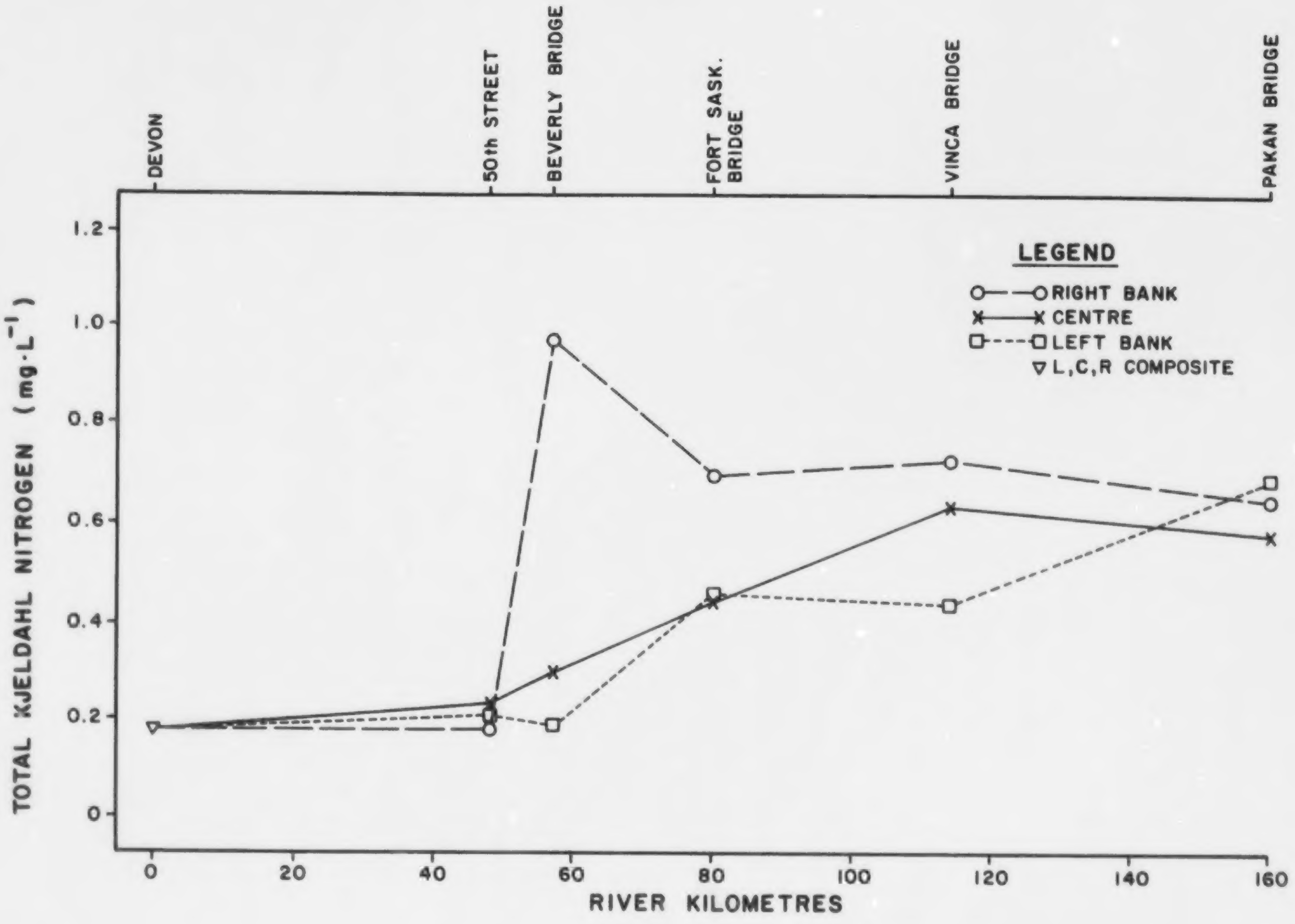

Fig. 11.5 Median Total Kjeldahl nitrogen values, North Saskatchewan River, 1983 - 1984.

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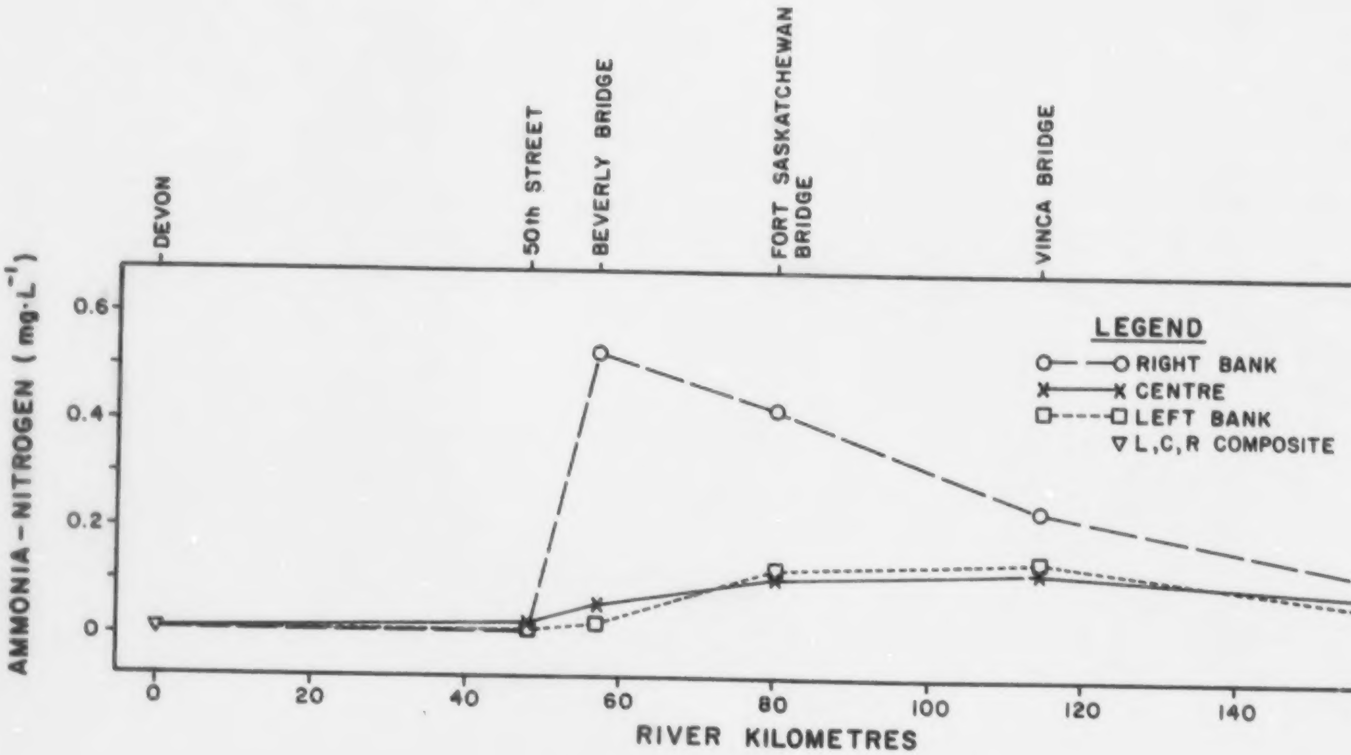

Fig. II.6 Median ammonia - nitrogen values, North Saskatchewan River, 1983 - 1984.

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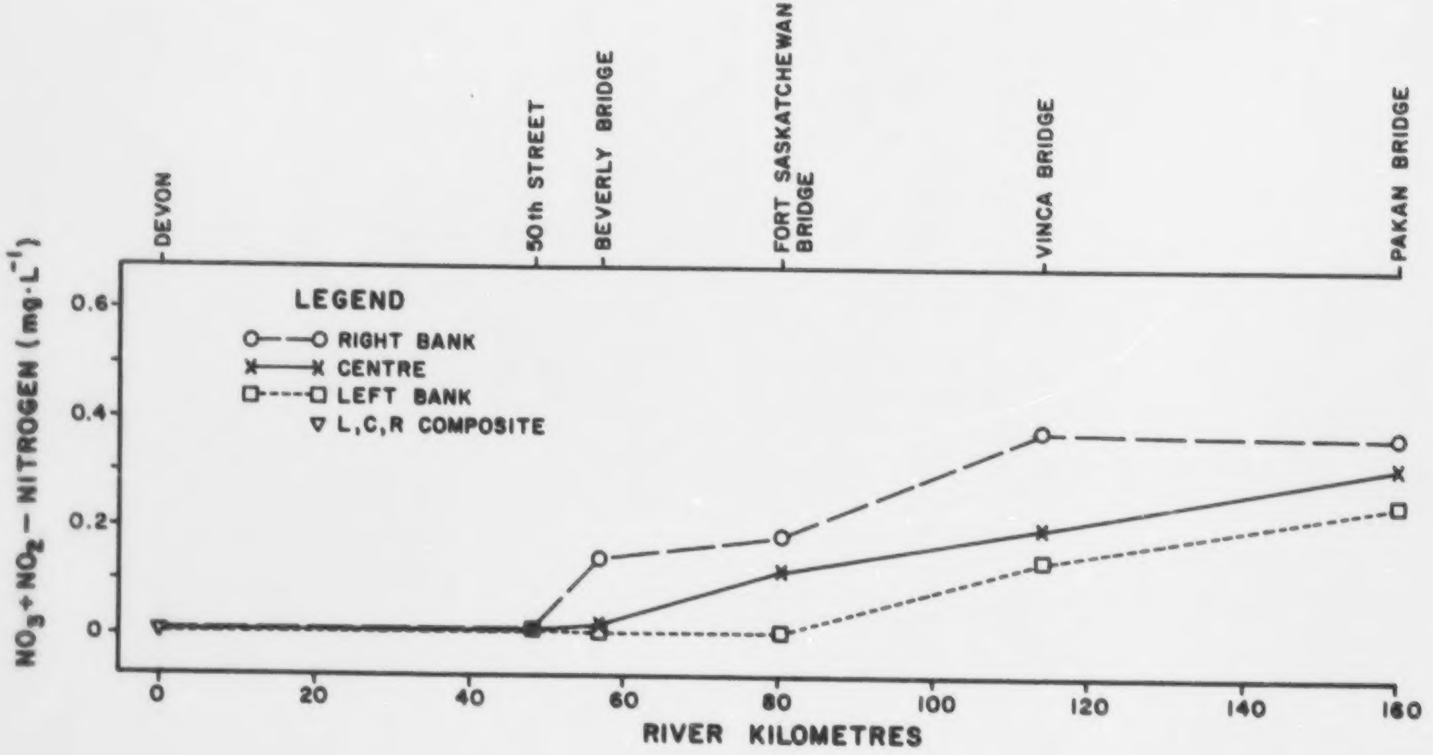

Fig. II.7 Median nitrate plus nitrite – nitrogen values, North Saskatchewan River, 1983 - 1984.

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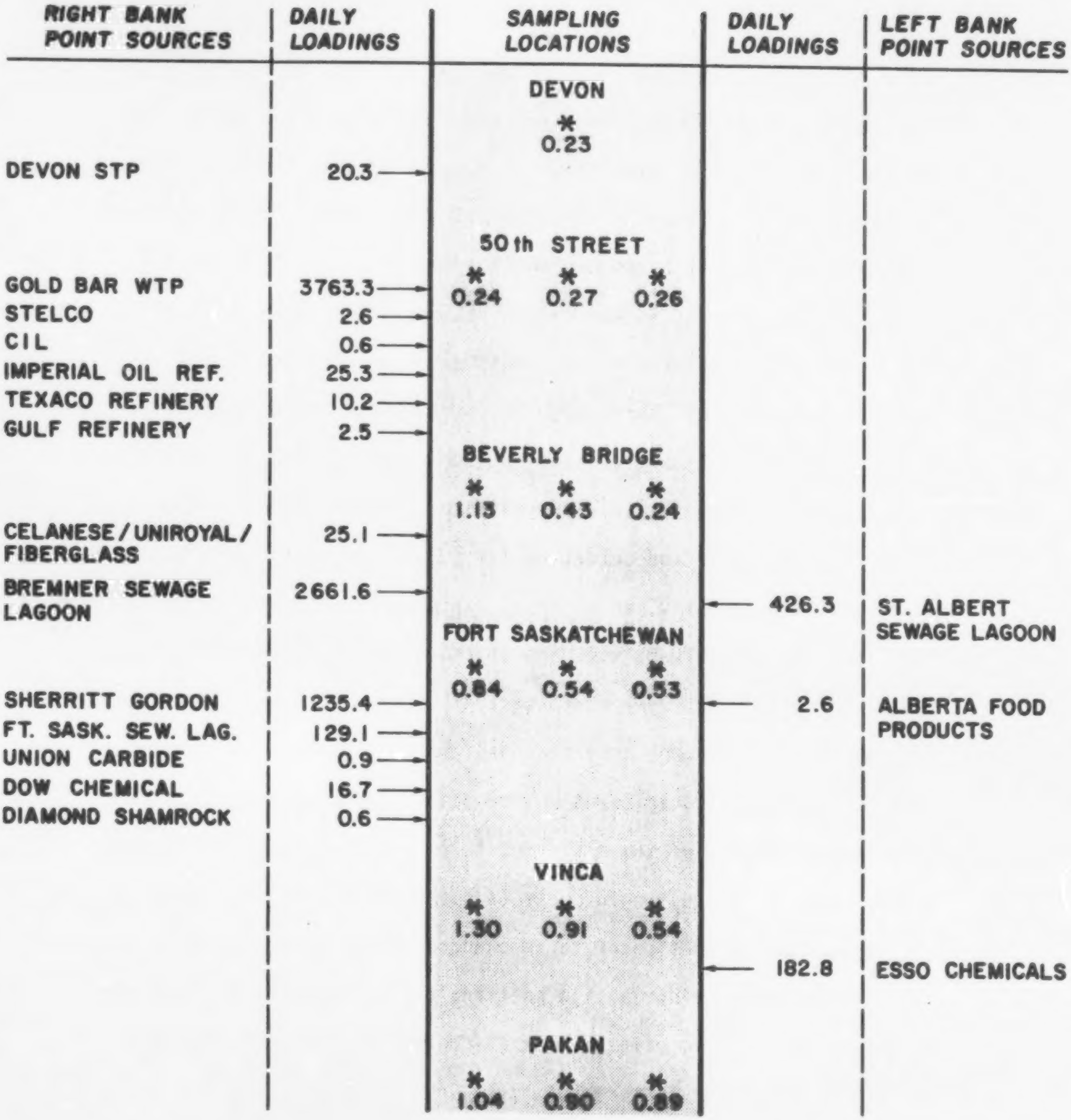
bank-to-bank differences were significant at Pakan ($P< 0.05$, $n = 11$), they were much smaller than those at Beverly Bridge, Fort Saskatchewan, or Vinca. Overall concentrations of all three forms of nitrogen were comparatively high at Pakan during 1983-1984.

Seasonal patterns in the concentrations of nitrogen forms were less clear than spatial patterns. Highest levels of TKN and NH_3-N occurred at Devon, all three 50th Street Footbridge sites, and Beverly Bridge left-bank and centre sites in late June and mid-July of 1983 when flows were highest. Nitrate+nitrite concentrations at these sites were less than the detection limits of 0.05 $mg \cdot L^{-1}$ on almost all occasions; consequently, no seasonal pattern was evident. At the Beverly Bridge right-bank site and at all sites downstream from Beverly Bridge, there were no consistent seasonal patterns of nitrogen concentration. Although some seasonal and spatial changes in the distribution of nitrogen forms may be attributable to the interconvertibility of the different forms as shown in the processes and pathways of the nitrogen cycle (e.g. see Odum 1971 or McNeely et al. 1979), an explanation of these changes will not be attempted here. The spatial distribution patterns of nitrogen forms in the NSR primarily result from point-source discharges of nitrogen, and major trends are discussed in terms of "total nitrogen" (Fig. 11.8).

Approximately 92% of all total nitrogen from continuous municipal and industrial point-source discharges enters the NSR on the right bank between the 50th Street Footbridge and Vinca. This is evident in the substantially higher total nitrogen concentrations measured at right-bank sites below the 50th Street Footbridge (Fig. 11.8). The


RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
0.23
DEVON STP
20.3
50th STREET
GOLD BAR WTP
3763.3
0.24
0.27
0.26
STELCO
2.6
CIL
0.6
IMPERIAL OIL REF.
25.3
TEXACO REFINERY
10.2
GULF REFINERY
2.5
BEVERLY BRIDGE
1.13
0.43
0.24
CELANESE / UNIROYAL / FIBERGLASS
25.1
BREMNER SEWAGE LAGOON
2661.6
426.3
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
0.84
0.54
0.53
SHERRITT GORDON
1235.4
2.6
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
129.1
UNION CARBIDE
0.9
DOW CHEMICAL
16.7
DIAMOND SHAMROCK
0.6
VINCA
1.30
0.91
0.54
182.8
ESSO CHEMICALS
PAKAN
1.04
0.90
0.89

TOTAL INDUSTRIAL LOAD = 1505.3
TOTAL MUNICIPAL LOAD = 7000.6
TOTAL DAILY LOAD = 8505.9

Fig. 11.8 Diagrammatic representation of 1983-84 median T. Nitrogen concentrations ($mg \cdot L^{-1}$) and estimated municipal and industrial point source loadings ($kg \cdot d^{-1}$) .

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more gradual increases in centre-channel and left-bank levels in the same region probably reflect both the slowness of lateral mixing and the smaller left-bank nitrogen loading, a pattern rather similar to that noted for total phosphorus. Excluded from the summary in Figure 11.8 are the estimates from intermittent or highly fluctuating point-source discharges, such as tributary streams.

Contributions from tributaries can be important during high-flow periods, especially from late June to mid-July. Table 11.1 includes an overview of the seasonal nature of total nitrogen loading from tributary sources calculated from data gathered in 1983. These tributaries accounted for 42% to 56% of total nitrogen loading from all sources during the late June to mid-July interval. Some of the seasonal variation in total nitrogen noted at the 50th Street Footbridge sites and Beverly Bridge left-bank and centre-channel sites, which were upstream from major continuous left-bank point-source inputs, was due in part to total nitrogen contributions from Whitemud Creek and other smaller tributaries such as Mill and Fulton creeks.

11.5 Surface Water Quality Objectives: Nitrogen

The Alberta Surface Water Quality Objectives (ASWQO) recommend a maximum total nitrogen concentration of 1.0 $mg \cdot L^{-1}$ in surface waters (Alberta Environment 1977). The Canadian Drinking Water Standards and Objectives (Department of National Health and Welfare 1969) recommend maximum concentrations of 0.5 $mg \cdot L^{-1}$ for NH_3-N and 10 $mg \cdot L^{-1}$ for NO_3-N + NO_2-N for the protection of domestic water supplies.

The toxicity of aqueous solutions of ammonia to fish and certain aquatic invertebrates has been attributed to un-ionized ammonia (Environmental Studies Board 1973). The concentration of un-ionized ammonia is dependent upon the concentration of dissociated ammonia (NH_4), pH, dissolved oxygen, and temperature; it can be calculated when these other values are known (Environmental Protection Agency 1976). Levels of un-ionized ammonia actually toxic to freshwater animal life range from 0.20 to 2.0 $mg \cdot L^{-1}$; therefore, a maximum concentration of 0.02 $mg \cdot L^{-1}$ un-ionized ammonia should be complied with in order to protect freshwater life (Environmental Studies Board 1973).

Median and maximum total nitrogen concentrations in the study section of the NSR in 1983 are summarized in Figure 11.4. The ASWQO of 1.0 $mg \cdot L^{-1}$ was exceeded primarily at right-bank sites in the vicinity of major effluent contributions and at the three most downstream sampling locations (Sturgeon River, Vinca and Pakan). At Pakan, the objective was exceeded in approximately 24% of the samples collected during 1983.

In 1983, the Environmental Studies Board (1973) objective of 0.02 $mg \cdot L^{-1}$ of un-ionized ammonia was exceeded three times at the Beverly Bridge right-bank site (0.02, 0.03, and 0.04 $mg \cdot L^{-1}$) and three times at the Sturgeon River right-bank site (0.02, 0.02, and 0.03 $mg \cdot L^{-1}$).

The objective was exceeded once in 1983 at the Beverly Bridge right-bank site (0.03 $mg\cdot L^{-1}$). In each of these cases, dissolved oxygen was at or near 100% saturation, so it was unlikely that there was any toxic effect on fish or aquatic invertebrates at that time.

During 1983, the Canadian Drinking Water Standards (Department of National Health and Welfare 1969) objective of 0.5 $mg\cdot L^{-1}$ NH_4-N for domestic water supplies was occasionally exceeded at the Beverly Bridge right-bank site and locations further downstream. At Pakan during this period, NH_4-N levels exceeded this objective in 12% of the samples. No objective for NH_3-N is included in the revised guidelines for Canadian Drinking Water Quality (Department of National Health and Welfare 1979).

Nitrate+nitrite nitrogen concentrations in excess of the Guidelines for Canadian Drinking Water Quality objective of 10 $mg\cdot L^{-1}$ were not measured in 1983.

11.6 Impacts: Nitrogen

High concentrations of nitrite-nitrogen (NO_2-N > 1.0 $mg\cdot L^{-1}$) can be toxic to man and other animals, and concentrations of nitrate-nitrogen (NO_3-N > 10 $mg\cdot L^{-1}$) can interfere with the oxygen-carrying capacity of the blood. Adherence to the surface water quality objective of 1.0 $mg\cdot L^{-1}$ total nitrogen (TN) would assure that neither of these forms reaches toxic levels.

As discussed above, high concentrations of ammonia-nitrogen (NH_3-N) can be lethal to fish and other forms of aquatic life. For this reason, the surface water quality objective for NH_3-N is usually lower than, and set separately from, that for TN.

All forms of nitrogen occurring in surface waters contribute to the fertility of the water, especially in the presence of adequate concentrations of available phosphorus. Excessive plant growth can occur when neither nitrogen nor phosphorus is limiting and other conditions are favourable. These relationships are discussed at more length in Sections 12.3 and 16.0.

12.0 CHLOROPHYLL-a

Most oxygen-evolving photosynthetic organisms have chlorophyll-a (chl-a) as a primary photosynthetic pigment. Because there is a direct relationship between the pigment concentration and the amount of cellular matter in plants, the chl-a concentration can be used as a relative measure of algal biomass or algal standing stock (e.g. Tett et al. 1978). By implication, chl-a concentrations are frequently synonymized with algal biomass or algal standing stock in published literature (e.g. Charlton et al. 1981).

In this study of the North Saskatchewan River (NSR), chl-a was measured for both the river phytoplankton (potamo-phytoplankton) and the epilithic algae. The latter are those algae attached to rocks in the river bed. The origin of potamo-phytoplankton in rivers is a controversial issue which has been discussed by Hynes (1972) and Whitton (1975). The general concensus is that most of the potamo-phytoplankton comes from benthic assemblies (including epilithic forms), and that another sizable fraction is due to inocula from lakes, backwaters, or slowly moving areas of a river. True planktonic species, which can only maintain populations in slowly moving waters, comprise a small fraction of the potamo-phytoplankton.

All sampling for chl-a was done in 1983 (see Table 4.5). For details of field and laboratory methods, see Section 5.0.

12.1 Potamo-phytoplankton: Results

The median potamo-phytoplankton biomass, measured as chl-a, increased consistently and significantly ($P<0.05$) throughout the 163-km study section of the NSR. Median chl-a concentrations at Pakan were 6 to 7 times higher than concentrations at Devon (Fig. 12.1). Although left-bank and centre-channel concentrations increased rather uniformly throughout the study section, right-bank values increased dramatically from 50th Street Footbridge to Beverly Bridge, and remained significantly higher at Fort Saskatchewan. Intersite differences diminished between the Vinca and Pakan locations.

Longitudinal differences in the chl-a concentrations were more pronounced during a low-flow period in the summer than during a similar low-flow period in the fall or during the spring-peak discharge:

	Devon	Pakan		Increase
	Composite	left	right	
	$mg.m^{-3}$	$mg.m^{-3}$	$mg.m^{-3}$	
Summer (Aug 2-3)	1.53	29.28	22.26	15 to 19x
Fall (Nov. 15-16)	0.57	6.10	5.14	9 to 11x
Spring (June 28-29)	2.53	3.72	2.18	0.9 to 1.5x

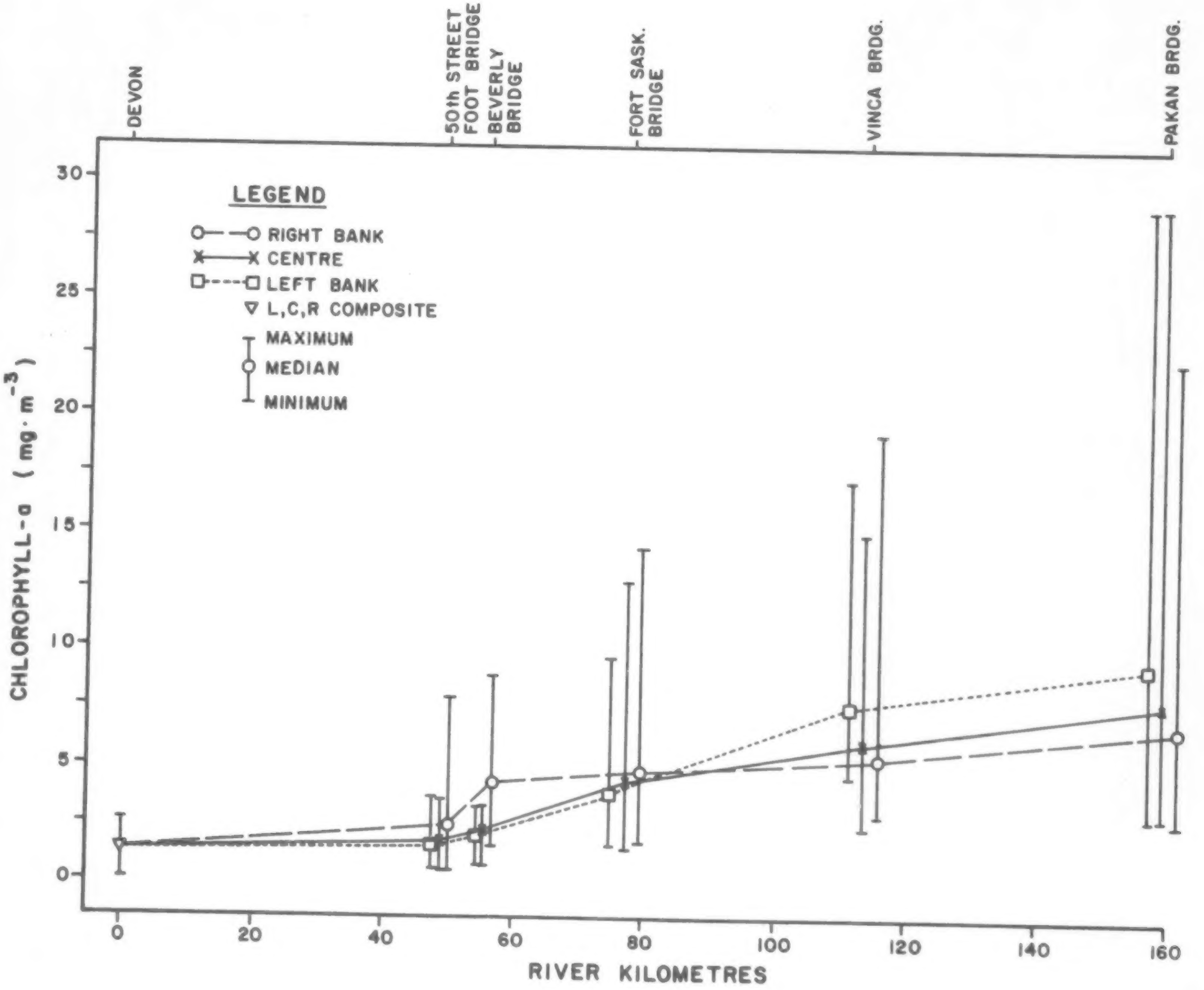

Fig. 12.1 Longitudinal trends in potamo-phytoplankton chlorophyll-a concentration of the North Saskatchewan River in 1983.

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Except at Devon, where potamo-phytoplankton chl-a concentrations were always low and where no clear pattern was evident, there was a trend throughout the study section of the NSR towards seasonal peaks in chl-a concentration. The largest peak occurred in mid-summer (usually early August); an intermediate peak occurred in spring (late May to early June); a smaller peak was evident in late fall. These peaks tended to increase in size in downstream direction and were usually separated by low concentrations of chl-a, especially in mid-June during the period of high flow. This pattern of seasonal change was most evident for right-bank sites, an overview of which is shown in Figure 12.2.

12.2 Epilithic Algae: Results

The longitudinal pattern of epilithic chl-a concentration in the study section of the NSR was similar to that of potamo-phytoplankton chl-a. The median epilithic chl-a concentration was 8 to 9 times higher at Pakan than at Devon (Fig. 12.3). However, the pattern followed by epilithic chl-a was frequently inconsistent from one sampling date to the next, obscuring trends and suggesting considerable spatial or temporal variability.

The increase in chl-a concentrations was not statistically significant ($P<0.05$, $n = 9$) between Devon and 50th Street Footbridge for either right-bank or left-bank samples. Although the medians were more than twice as high at 50th Street Footbridge, the ranges of values and inconsistencies were much greater at 50th Street Footbridge

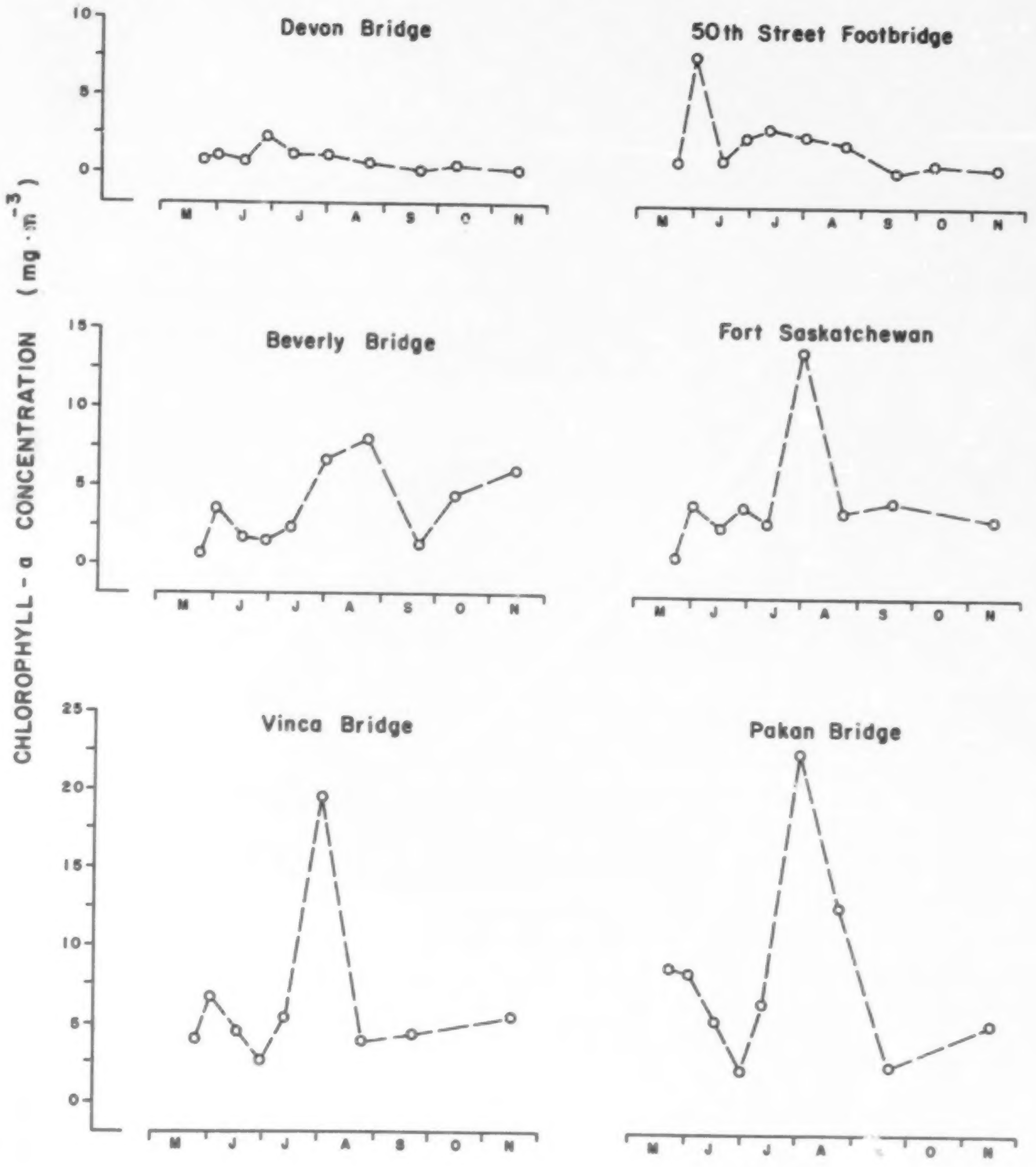

Fig. 12.2 Seasonal pattern of potamo-phytoplankton chlorophyll-a concentration at right bank sites of the North Saskatchewan River in 1983.

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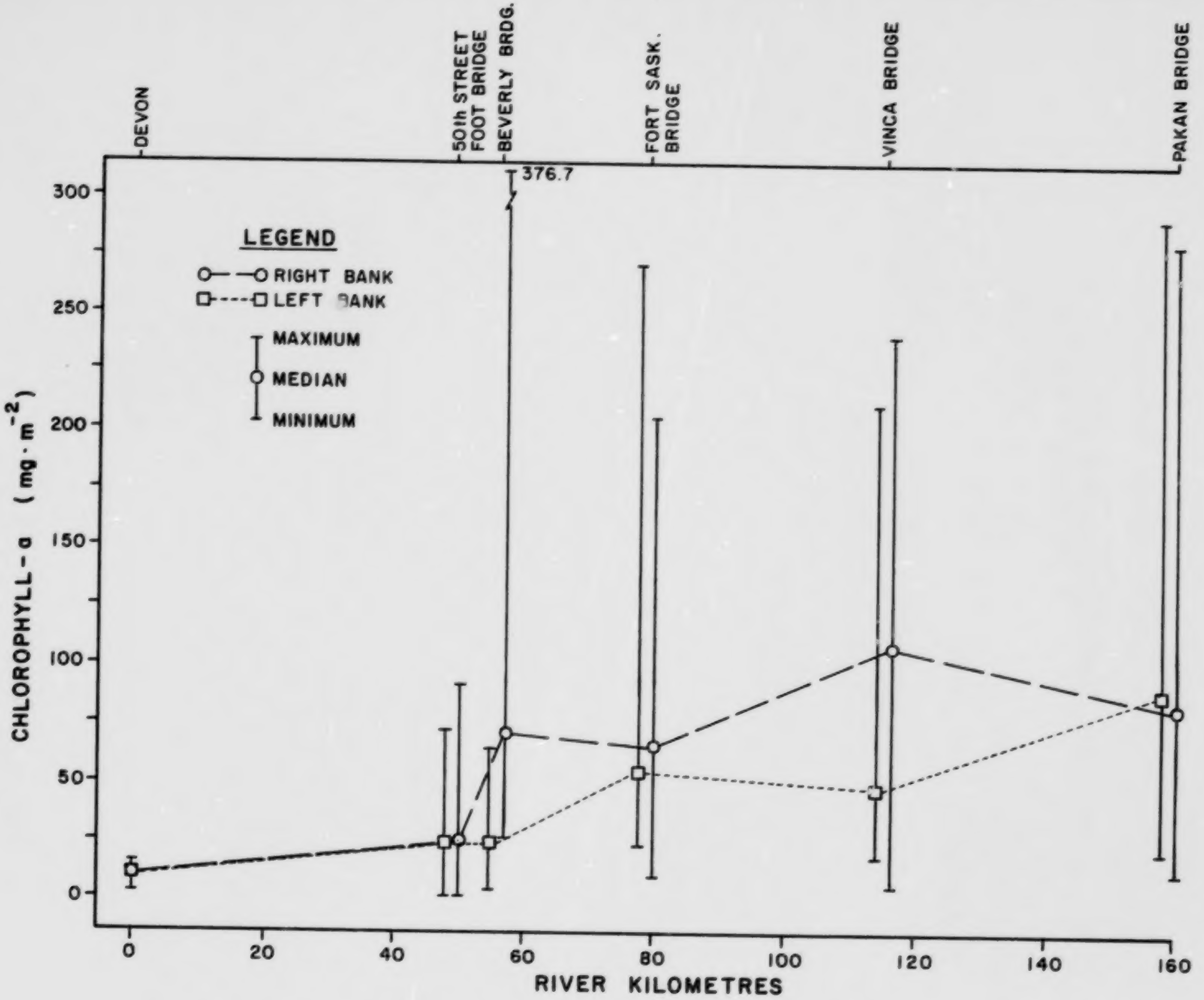

Fig. 12.3 Longitudinal trends in epilithic chlorophyll-a concentration of the North Saskatchewan River in 1983.

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than at Devon. The first significant increase occurred between 50th Street Footbridge and Beverly Bridge on the right bank, and between Beverly Bridge and Fort Saskatchewan on the left bank ($P<0.05$, $n = 9$). Concentrations of epilithic chl-a were fairly constant from Fort Saskatchewan through Vinca to Pakan, although variability was high. For these three locations, bank-to-bank differences were not significant ($P<0.05$, $n = 9$).

The seasonal pattern of chl-a distribution was more distinct at locations downstream than upstream of Beverly Bridge. At upstream locations, algal standing stocks remained relatively low and stable throughout the sampling period. At the Beverly Bridge right-bank site and at all locations downstream, epilithic chl-a reached a first maximum in June (between the local runoff and mountain runoff peaks) and a second maximum from late August to early November. An overview of right-bank data is given in Figure 12.4. The spring peaks for both potamo-phytoplankton and epilithic algal chl-a coincided, but the "summer" epilithic maximum lagged several weeks behind the potamo-phytoplankton peak. This was probably due to scouring and related effects during the maximum flow period in late June and early July, as discussed below, as well as to the slower re-establishment rate for epilithic species over planktonic species.

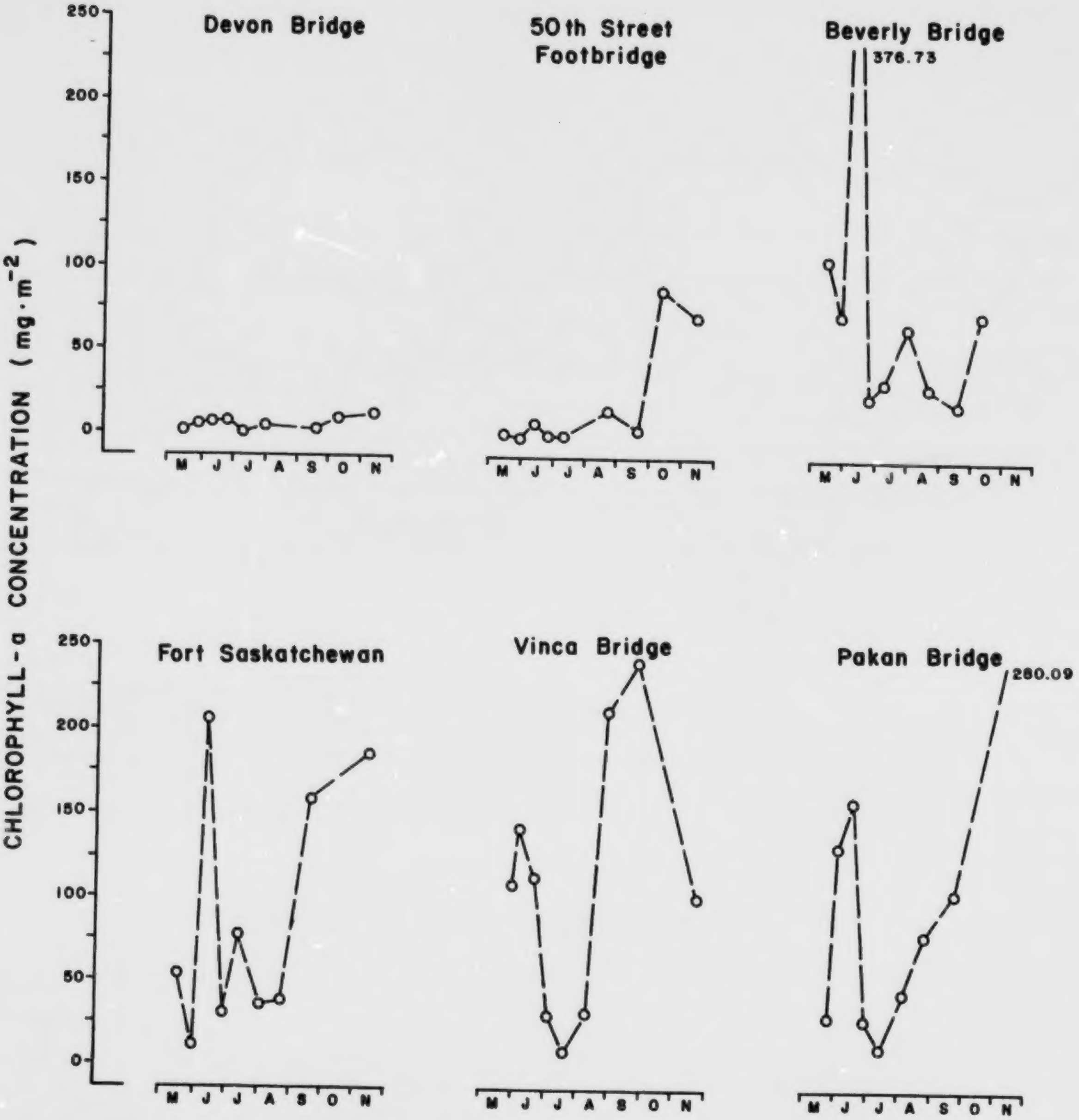

Fig. 12.4 Seasonal pattern of epilithic algal chlorophyll-a concentration at right bank sites of the North Saskatchewan River in 1983.

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12.3 Discussion: River Chlorophyll-a

The total amount of material transported by rivers tends to increase gradually and naturally in downstream direction (e.g. Hynes 1972). As current velocity decreases and loads of dissolved solids increase, plankton concentrations also tend to increase. Although a downstream increase in chl-a in the NSR may be due in part to natural causes, it is undoubtedly influenced by urban and industrial development in the vicinity of Edmonton. In this study, the most obvious change in chl-a values that could be linked to these developments was the doubling of epilithic and planktonic chl-a in the 5 km river section between 50th Street Footbridge and Beverly Bridge on the right bank. The major effluent entering the NSR between these two sites is from the Gold Bar Wastewater Treatment Plant (GBWTP), which enters the river on the right bank. A comparable increase in chl-a on the left bank occurred about 24 km downstream of Beverly Bridge at Fort Saskatchewan, probably the result of the combined effects of discharges from the St. Albert sewage lagoons and lateral mixing in the NSR, which could have allowed effects of the GBWTP effluent to extend to the left bank. Similar increases in chl-a concentrations in the Oldman River below Lethbridge, and in the Bow River below Calgary, have been attributed to nutrients in sewage treatment plant effluents (e.g. Davies _et al_. 1977, Hamilton 1983).

Because chl-a was monitored for only six months of one year in the NSR (May to November, 1983), it is unwise to generalize from patterns found in 1983, especially because it was a year of atypical discharge (see Section 2.4). There was an inverse relationship between chl-a concentrations and seasonal discharge which, in the NSR as in many other rivers (e.g. Hynes 1972, Lack 1971, Tett _et al_. 1978), was likely the main factor regulating algal standing stock. On the other hand, chl-a patterns showed a direct relationship with temperature and light. Consequently, the relative contributions of direct and inverse factors on algal development were difficult to assess.

Phytoplankton chl-a peaks are common in spring after ice melt when rising temperatures, clear water, higher light intensity, and greater day length favor the development of algal populations. Increases in river flow rates due to local and mountain runoff suppress the development of algal populations. Increases in velocity result in a shorter residence time for potamo-phytoplankton and increases in water volume reduce algal density through dilution. Attached algae are removed by faster currents as a result of the scouring effect of silt-laden water (Hynes 1972).

In the NSR, planktonic chl-a concentrations began to increase soon after the decline in spring high flows and reached a peak in early August, when temperatures were highest and light conditions were optimal. The lag in the recovery of epilithic chl-a relative to planktonic chl-a suggested that epilithic algae were affected by the persistent effects of peak discharges. The NSR is usually extremely turbid during high flow periods (Patterson and Nursal 1975). This was the case in 1983, as indicated by a sharp peak in the non-filterable residue (NFR) content of the river during high-flow periods. However, NFRs returned to normal levels when flow rates dropped. Scouring and light inhibition due to heavy silt loads were the most probable causes of chl-a reduction during this period. When flows decreased, a considerable amount of silt was deposited on the substrate, smothering the attached algae that remained after scouring, and further retarding recovery.

Differences in longitudinal, potamo-phytoplankton chl-a concentration were most accentuated during the summer low flow period, when the residence time of phytoplankton was long, and light and temperature conditions were near optimal. Algal growth under these conditions was more likely to be limited by nutrient concentrations than by physical factors. The much higher chl-a concentrations downstream of Edmonton reflected the higher nutrient concentrations below the city. Differences in upstream-downstream nutrient levels persisted during the fall, but all algal growth was inhibited by dropping temperatures and lower light intensities. The "flushing" effect of peak flows was the main determinant of algal standing stock during the spring.

12.4 Surface Water Quality Objectives

No water quality guidelines or objectives for photosynthetic pigment concentrations have been established by provincial (Alberta Environment 1977) or federal (see McNeely et al. 1979) authorities. In the absence of guidelines or objectives, chl-a data will be discussed in terms of their importance in relation to eutrophication, nutrient levels, and potential dissolved oxygen depletion.

Planktonic chl-a concentration is one of the variables that has been used in the trophic classification of lentic habitats (Wetzel 1975, OECD 1982). In its 'fixed boundary system', the OECD (1982) proposed the following boundaries:

	mean chl-a ($mg.m^{-3}$)	peak chl-a ($mg.m^{-3}$)
ultra-oligotrophic	<1.0	<2.5
oligotrophic	<2.5	<8.0
mesotrophic	2.5 - 8	8 - 25
eutrophic	8 - 25	25 - 75
hypertrophic	>25	>75

A comparable classification system has not been published for lotic habitats, so the classification for lentic habitats has been applied occasionally to lotic habitats for comparative purposes (e.g., Davies et al. 1977). Because comparisons between different systems are not necessarily valid, the application of this classification to rivers may be largely academic in value. This point is made by Hynes (1969), who indicates that running water is more "fertile" than standing water of the same chemical quality because turbulence prevents the formation of nutrient depleted zones around plants.

If the fixed boundary system proposed by the OECD for the trophic classification of lentic waters is applied to the 1983 NSR data, the river water at Devon would be classified as ultra-oligotrophic on the basis of mean chl-a concentrations, or as oligotrophic on the basis of peak chl-a values. At Pakan, the water would be classified as eutrophic on either basis.

An attempt to classify the rivers of southern Alberta according to their trophic status was made by Hamilton (1983), who proposed a classification system based upon the carbon content of epilithic algae. He suggested a chlorophyll-to-carbon ratio of 20:1 as an acceptable conversion factor, but recognized that this ratio can vary considerably (H.R. Hamilton, pers. comm.). The proposed classification based on epilithic carbon or chl-a concentration has the following boundaries:

	mean carbon ($mg.m^{-2}$)	mean chl-a ($mg.m^{-2}$)
oligotrophic	<0.5	<10.0
mesotrophic	0.5 - 5	10 - 100
eutrophic	5 - 20	100 - 400
hypertrophic	>20	>400

In 1983, the NSR at Devon fell into the higher range of the oligotrophic category according to the above classification system. The river was mesotrophic at the 50th Street Footbridge, and remained in the lower range of this category at Beverly Bridge. Although the chl-a concentration increased further downstream, the river remained mesotrophic, with the exception of the Vinca Bridge right-bank site, which would have been considered eutrophic under this system.

12.5 Impacts

The potamo-phytoplankton and epilithic algal chl-a concentrations in the NSR between Devon and Pakan were generally low to moderate and, as indicators of algal abundance, were not a major cause for concern prior to the conclusion of this study. However, the perpetuation of present nutrient levels or any increase in nutrient levels, combined with decreased scouring and increased clarity due to low flows, is likely to enhance algal growth. Enhanced epilithic growth would contribute to substrate fouling, and could contribute to nocturnal dissolved oxygen reduction in summer and to lower dissolved oxygen levels in winter.

Between sundown and sunrise, autotrophic oxygen production from photosynthesis is greatly reduced or absent, whereas oxygen consumption due to respiration continues in both autotrophic and heterotrophic organisms. Consequently, there can be a nocturnal decline or total depletion of dissolved oxygen when algal standing stocks are high. This situation is most likely to occur in summer months when oxygen solubility is lowest due to high temperatures.

In winter, dissolved oxygen levels may decline throughout the 24-hour day. Photosynthesis is inhibited by low temperatures, and by low light levels due to the combined effects of short days, ice cover, and snow cover; reoxygenation from the atmosphere is also inhibited by ice cover. Oxygen consumption can be high because of the respirational demands of living organisms and because of the decomposition of accumulated organic materials.

13.0 CARBON

Carbon is a major constituent of the aquatic environment. In natural waters, most inorganic carbon occurs as dissociation species of carbonic acid in a dynamic equilibrium affected by atmospheric conditions and by the respiration and photosynthesis of living organisms. Organic carbon occurs as dissolved compounds in the water and as cells of, and breakdown particles from, living and dead organisms.

In this study, sampling for inorganic and organic carbon was done on the same schedule (Tables 4.4, 4.5) as sampling for major ions and nutrients: 11 mainstem North Saskatchewan River (NSR) locations on 12 dates in the 1982 study; 6 mainstem NSR locations on 12 dates in the 1983 study which was extended to include two winter dates in 1984. Municipal sewage treatment plant effluents, industrial effluents, and major tributaries were sampled in 1983 only; sampling dates are summarized in Table 4.6.

Total organic carbon (TOC) was analyzed by the City of Edmonton laboratory until the end of November, 1982; the Alberta Environmental Centre (AEC) laboratory at Vegreville performed analyses for dissolved organic carbon (DOC) and total particulate carbon (TPC) from August 1982 until March 1984. In most natural waters, TPC is approximately equivalent to particulate organic carbon (F. Dieken, AEC pers. comm.). For three data sets in the fall of 1982, the total organic carbon results from the two laboratories were significantly different ($P<0.001$, $n = 41$). Therefore, 1982 and 1983 data are not comparable, and only 1983 organic carbon data are treated further. Additional details on sampling and analysis are given in Section 5.0.

13.1 Results and Discussion: Inorganic Carbon

Values for dissolved inorganic carbon (DIC) showed no clear spatial or temporal pattern or trend in the study section of the NSR in 1982 or 1983. Concentration ranges and medians were similar in samples from locations upstream and downstream of the City of Edmonton:

Location	Range	Median
Devon (1)	29 to 35.8 $mg \cdot L^{-1}$	32 $mg \cdot L^{-1}$
Beverly Bridge (6)	29 to 36 $mg \cdot L^{-1}$	33 $mg \cdot L^{-1}$
Pakan (11)	28 to 37 $mg \cdot L^{-1}$	33 $mg \cdot L^{-1}$

The distribution and ranges of values for DIC in the study section of the NSR suggest strongly that DIC concentrations are unaffected by municipal, industrial, or tributary inputs in the vicinity of the City of Edmonton.

13.2 Results and Discussion: Organic Carbon

Total organic carbon (TOC) concentrations tended to vary with the volume of river flow (Fig. 13.1; $r^2 = 0.63$ for Beverly Bridge centre site). Of the total carbon in the river water, only the dissolved organic fraction (DOC) seemed to be affected by municipal treatment plant and industrial effluents and by discharges from tributary creeks. High values during peak flows were largely attributable to inputs from runoff; DOC values were consistently higher in tributary creeks and rivers than in the mainstem NSR.

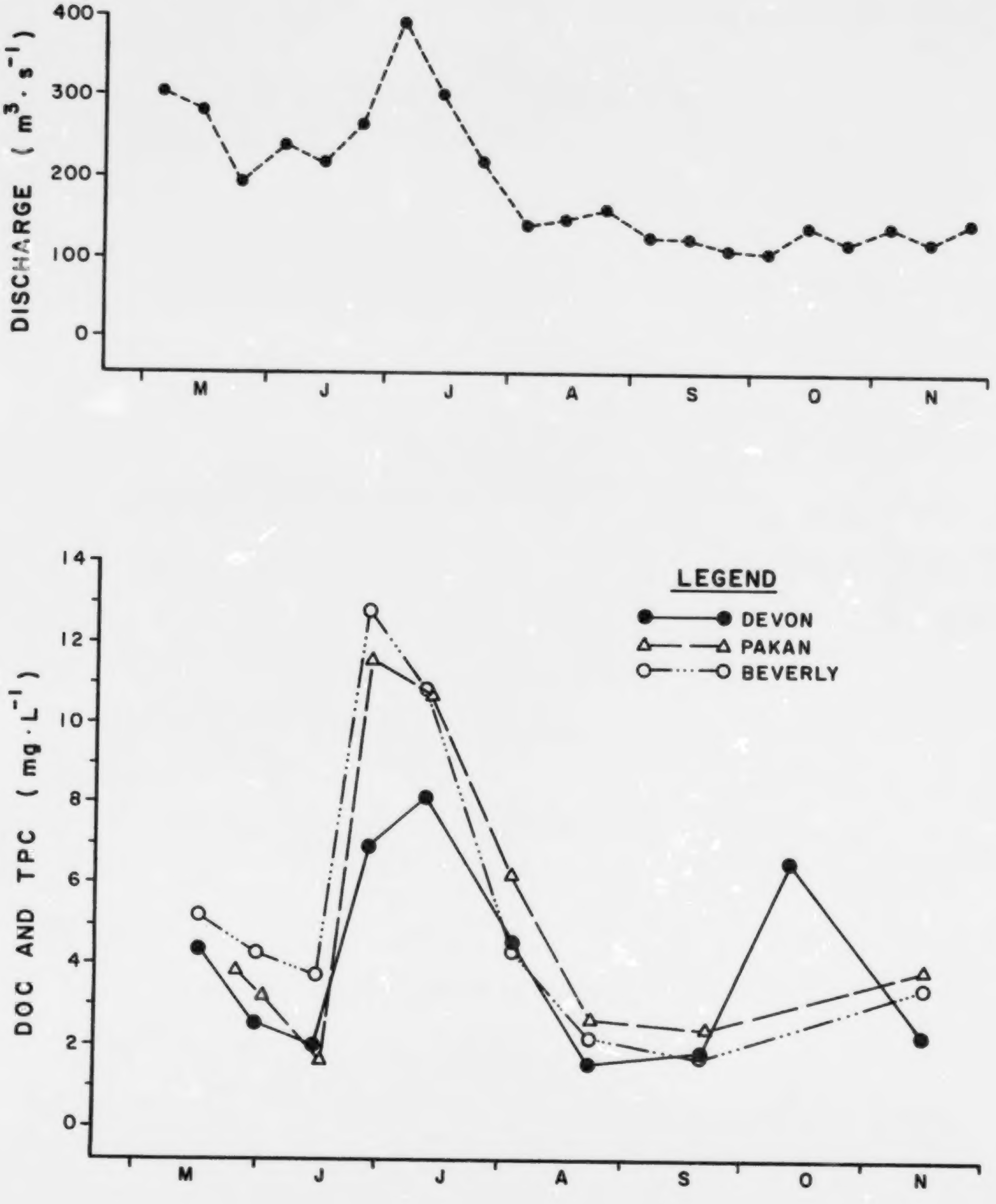

Fig. 13.1 DOC and TPC in the NSR at Devon, Beverly and Pakan ; and NSR discharge at Edmonton, 1983. L, C & R samples averaged.

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Median DOC values for each sampling location from Devon to Pakan for 1983 are shown in Figure 13.2. Values from center-channel sites increased in a downstream direction between Devon and Pakan, but values from left-bank sites remained at background level (Devon) through the City of Edmonton. A large increase in left-bank DOC values was observed between Fort Saskatchewan and Vinca ($P<0.05$, $n = 13$). The high values at all sites at Vinca reflects inputs from the Sturgeon River (median 1983 DOC = 16 $mg \cdot L^{-1}$, $n = 9$) and the Redwater River (median 1983 DOC = 20 $mg \cdot L^{-1}$, $n = 9$), as well as municipal effluents which entered the NSR downstream of Edmonton. The median DOC value increased sharply at the Beverly Bridge right-bank site downstream of the Gold Bar Wastewater Treatment Plant (GBWTP), and was significantly higher than the left-bank median value ($P<0.01$, $n = 12$). As Figure 13.2 shows, highest median values were observed at Pakan. The Devon and Pakan DOC data sets were significantly different ($P<0.05$, $n = 14$).

The summary of median TPC values for 1983 given in Figure 13.3 suggests both longitudinal and bank-to-bank differences. However, the range of values was large for and inconsistent among all locations and sites, and there were no significant differences between data sets for any of the sampling locations, including those for Devon and Pakan ($P>0.10$, $n = 14$). Additionally, there were no significant bank-to-bank differences in TPC values, even when median values appeared quite different, as was the case for Beverly Bridge ($P>0.5$, $n = 12$).

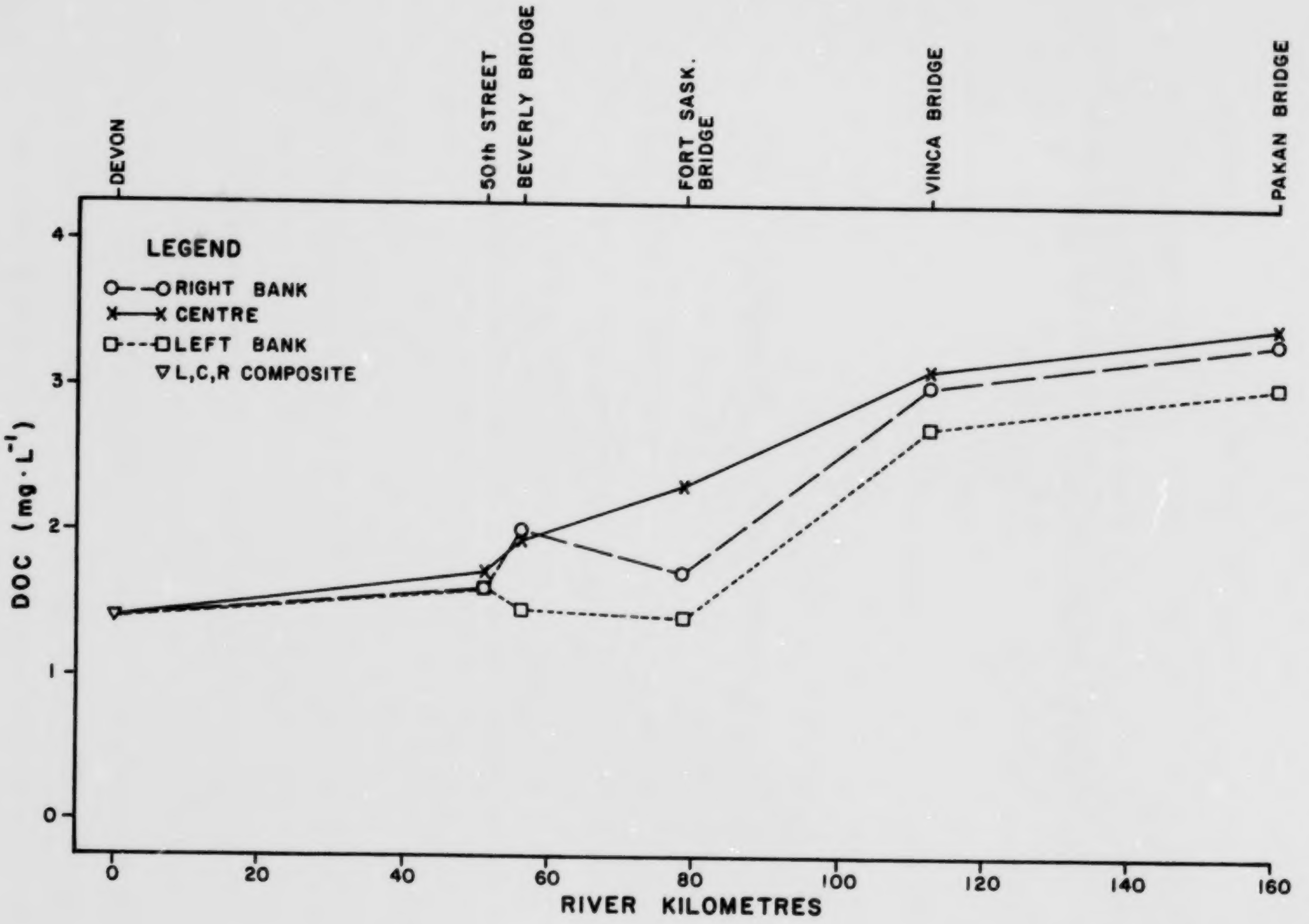

Fig. 13.2 Dissolved Organic Carbon in the NSR. Median values May-November, 1983.

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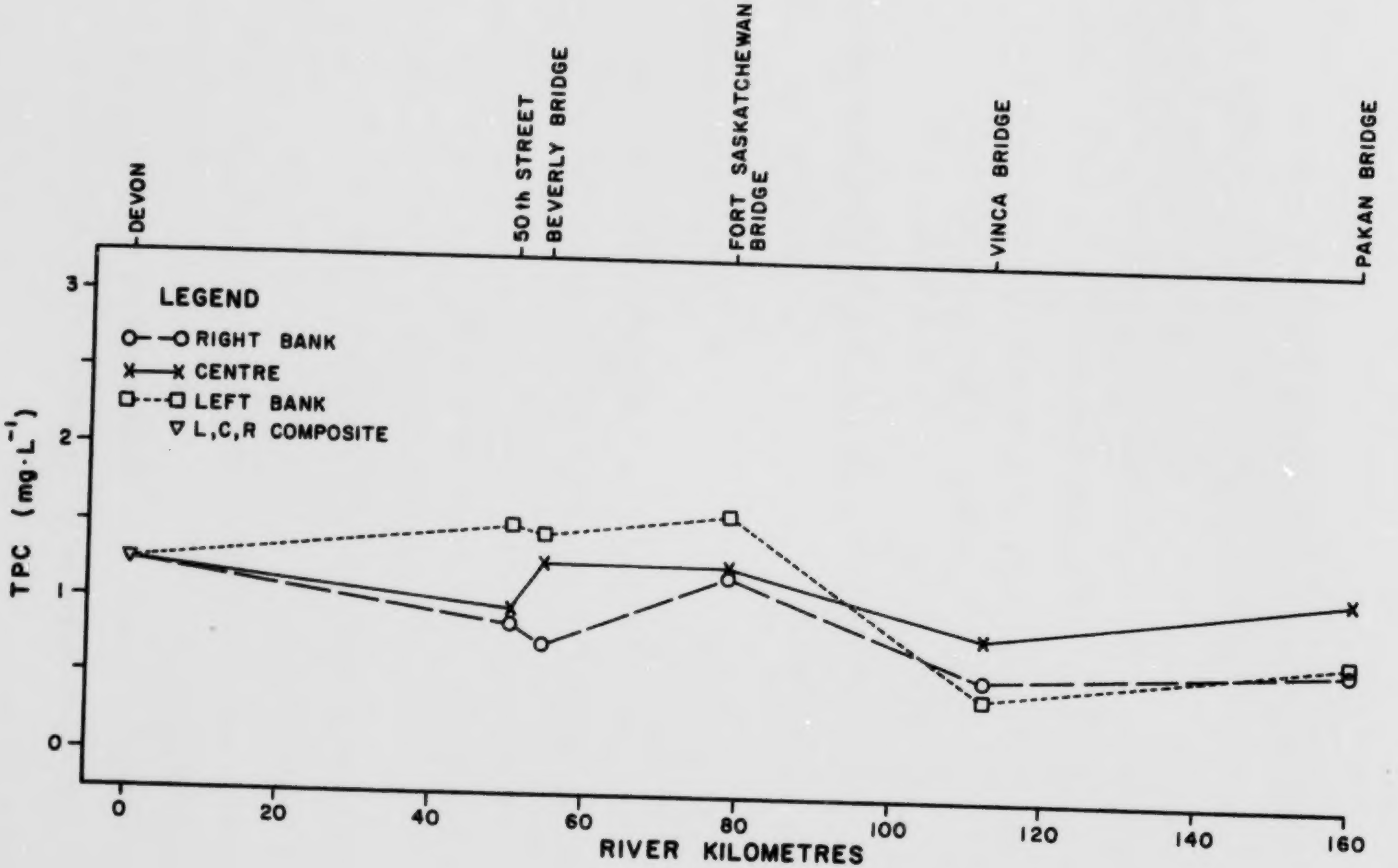

Fig. 13.3 Total Particulate Carbon in the NSR. Median values May-November, 1983.

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The River Water Quality Monitoring Network data for particulate organic carbon (POC) collected at Devon during the same period were significantly lower than those collected at Pakan ($P<0.005$, $n = 7$). The POC data from the River Water Quality Monitoring Network and from the present study were similar during the peak-flow period from late June to early July, when values at Pakan were more than double those at Devon. During low flows, however, values fluctuated greatly and the two sets of data were less similar.

There were no clear relationships between municipal or industrial discharges and particulate carbon.

13.3 Surface Water Quality Objectives

There are no Alberta Surface Water Quality Objectives (ASWQO) for DIC, nor have DIC concentration limits been set in any federal criteria (McNeely et al. 1979). However, there is a close relationship between DIC and alkalinity. Alkalinity values in the range of 30 to 500 $mg{\cdot}L^{-1}$ $CaCO_3$ equivalent are considered acceptable in surface waters (Department of National Health and Welfare 1969). This is roughly equivalent to a DIC range of 4 to 60 $mg{\cdot}L^{-1}$. For the protection of life in the aquatic environment, guidelines stipulate that alkalinity should be maintained near natural background levels with no sudden variations (Environmental Studies Board 1973). The DIC levels in NSR water measured in the present study fell within acceptable limits.

There are no ASWQO for organic carbon. The median DOC concentrations in the study section of the NSR were 1.0 $mg \cdot L^{-1}$ at Devon, and ranged from 1.05 to 1.9 $mg \cdot L^{-1}$ at Beverly Bridge, and from 2.05 to 3.4 $mg \cdot L^{-1}$ at Pakan, all well below the world average of 5.8 $mg \cdot L^{-1}$ in rivers (Wetzel 1983). However, the almost doubling of mean DOC values from 50th Street to the Vinca Bridge was indicative of organic enrichment.

13.4 Impacts

The presence of considerable concentrations of TOC in surface waters can add greatly to the biochemical oxygen demand (BOD) in the waters.

Particulate organic matter, which is often high in carbon content, may serve as a food substrate for bacteria. Organic particles and their bacterial flora are the major food source for a number of invertebrate groups, such as certain species of oligochaetes, dipteran larvae, and caddisfly larvae. The first two groups are often found in moderate to huge numbers in those sections of rivers immediately downstream of organic enrichment inputs. As noted in Part II of this report (zoobenthos), this may be the explanation for large numbers of oligochaetes at the site below the GBWTP and the sites downstream of Fort Saskatchewan.

14.0 BACTERIA

Microbiological samples collected during 1982-83 were analyzed for total coliform bacteria, fecal coliform bacteria, fecal streptococci and a general group known as heterotrophic bacteria. Coliform bacteria are widely used as a surrogate to indicate the presence of warm-blooded animal wastes and the potential of exposure to pathogenic organisms associated with the wastes. Pathogenic organisms are usually excreted in numbers which are several orders of magnitude smaller than those for coliform bacteria.

The total coliform (TC) group includes all aerobic and facultatively anaerobic, gram-negative, non-sporeforming, cytochrome oxidase negative, rod-shaped bacteria that ferment lactose with gas formation within 48 hours at 35°C. Many coliforms are ubiquitous in the environment; they are common in both soil and water and can multiply outside the intestinal tracts of animals. TC data have been used historically for determining long-term trends and assessing the general bacteriological quality of drinking water. Because these bacteria have many sources, however, they are not reliable as indicators of fecal contamination.

The fecal coliform (FC) group includes those coliforms capable of forming gas within 24 hours at 44.5°C. FC bacteria are the primary surrogate indicators of the bacteriological quality of recreational or raw water (Department of National Health and Welfare 1979) and their presence suggests contamination of intestinal origin, either from humans or other warm-blooded animals. The use of coliforms as indicators of fecal contamination is open to considerable debate, but it is traditionally continued because of the ease of sample collection and analysis, and because results are readily comparable with established water quality standards and historical data.

Fecal streptococci (FS) are large, ovoid, gram-positive, chain bacteria that are present in the feces of humans and all warm-blooded animals. Fecal streptococci are more resistent to natural and technological purification processes than are coliforms and, therefore, are assumed to be better indicators of pollution at distances from the source where coliforms would no longer be present. Some studies (see Department of National Health and Welfare 1983) have shown a correlation between high FS numbers and illness rates in persons using recreational waters. Although these studies are somewhat inconclusive, they suggest that FS may be better surrogate indicators of potential virus presence than are the coliforms (McNeely et al. 1979).

Fecal streptococci are sometimes used in conjunction with fecal coliforms to determine whether a pollution source is of human or non-human origin. Geldreich and Kenner (1969) proposed that a FC:FS ratio above 4 indicates a human source, whereas a ratio below 0.7 indicates fecal material from domestic animals. They suggested that this ratio is only applicable during the first 24 h that the bacteria are in the river. Wheater et al. (1979) question the reliability of such ratios, because they vary with season, human population, type of animal contaminating the water, and differential die-off rates of the bacteria. With some reservations, FC:FS may be helpful in determining the source of contamination when bacterial numbers are high.

Another group of bacteria found in water are the heterotrophs. This is a heterogenous group of aerobic and facultative anaerobic organisms that will grow on tryptose-glucose extract agar. The number of colonies counted on a plate of such medium is called the Standard Plate Count and is expressed as numbers per millilitre of sample water. Under given conditions, the Standard Plate Count, as an indicator of heterotrophic bacterial abundance, may be proportional to the amount of organic enrichment, the length of time organic matter has been in the water, and the general biological activity in the sample. It is believed that the Standard Plate Count greatly underestimates the numbers of heterotrophic bacteria present in running waters, because all species do not grow equally well under the standard conditions (Hynes 1972).

Bacteriological samples collected in 1982 and 1983 were analyzed by the Environmental Protection Service, Environment Canada, Edmonton. The membrane filtration (MF) technique was used for TC, FC and FS bacteria; heterotrophic bacteria were enumerated as a Standard Plate Count (Bell 1983). Additional comments on methods are included in the general methods section.

The two standard procedures used for analyzing indicator bacteria are the most probable number (MPN) technique and the membrane filter (MF) technique. The MF technique is fast and efficient, highly reproducible, and can be used for a variety of natural waters. However, when turbidity in the sample is high, the filter may clog before a sufficient volume of water has passed through.

Furthermore, when numbers of non-coliform bacteria are high or when toxic substances are present, the estimated number of coliforms may be low (American Public Health Association et al. 1980). Although these limitations may have affected a sample occasionally during the study, the MF technique has been used for several years on the NSR by the Environmental Protection Service, Environment Canada, Edmonton. The possible limitations of the MF test are far outweighed by its efficiency and reliability compared to the MPN test (F. Zaal, pers. comm).

14.1 Results and Discussion: Seasonal Trends

Although the bacteria data fluctuated to some extent over the two study years, seasonal patterns were discernible in most of the data sets. Figures 14.1 to 14.3 present seasonal data for TC, FC, and FS collected in 1982 and 1983 at the upstream location (Devon), a mid-city location (Beverly Bridge), and the most downstream location (Pakan) in the study section of the NSR.

At Devon, counts for all three indicator groups were somewhat elevated during the period of highest water flow from late June to early July, both years. Agricultural runoff during precipitation events and soil bacteria are probably the main contributors to these high counts, since the FC:FS ratio was below 0.7 for all samples. In 1982, numbers increased in August, when flow in the river was low. The source of these bacteria is unknown. The closest municipal

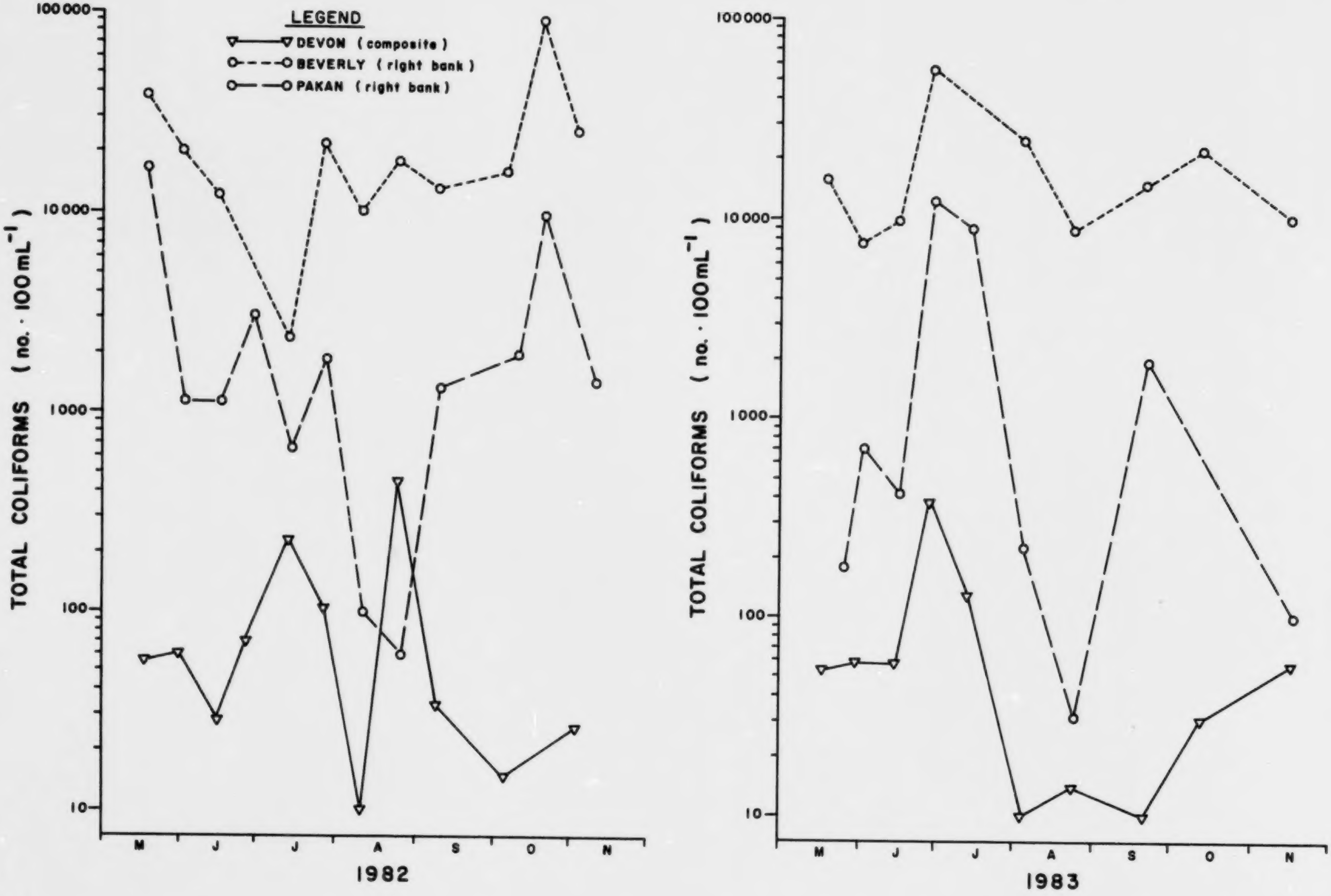

Fig. 14.1 Total Coliforms in the NSR at Devon, Beverly bridge and Pakan, 1982 and 1983.

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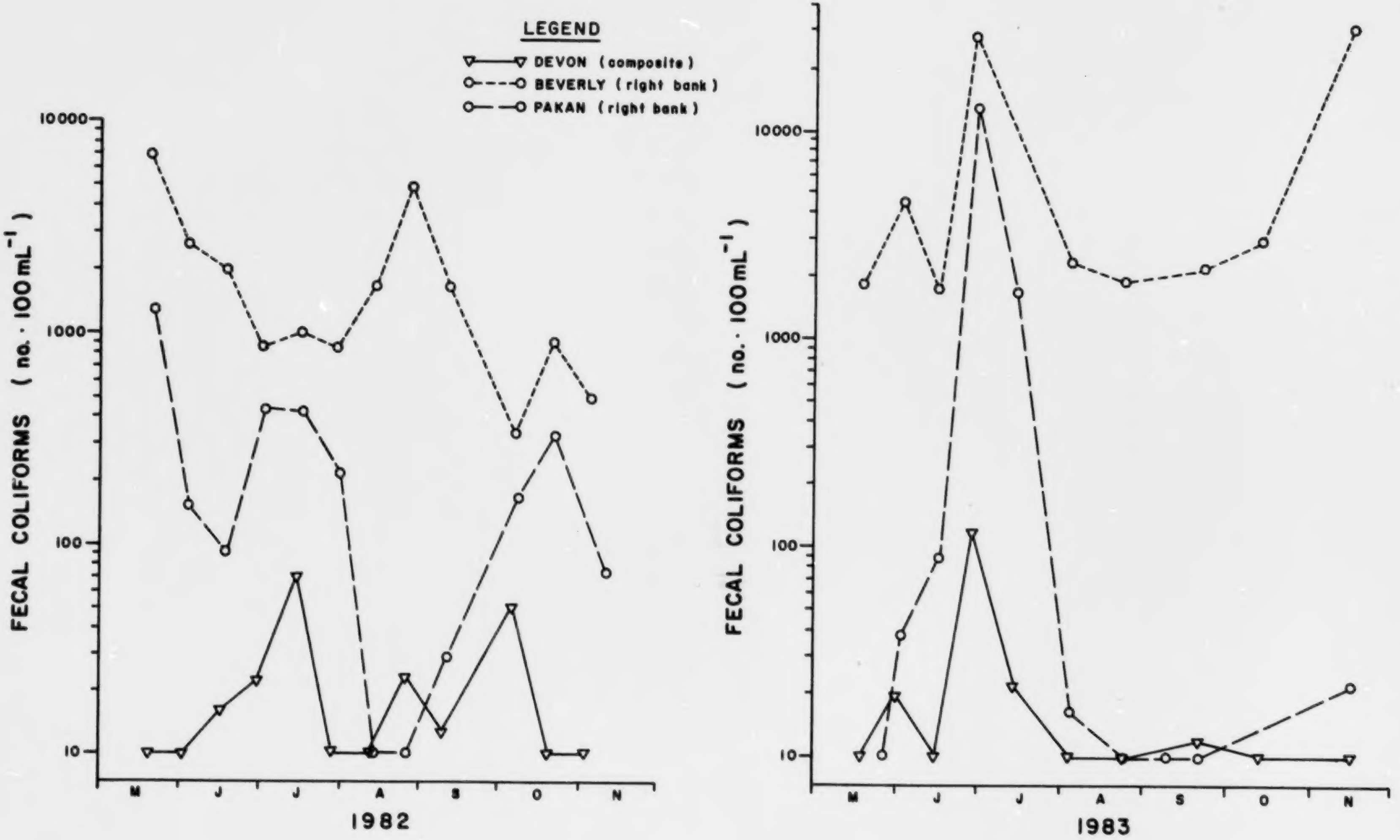

Fig. 14.2 Fecal Coliforms in the NSR at Devon, Beverly bridge and Pakan, 1982 and 1983.

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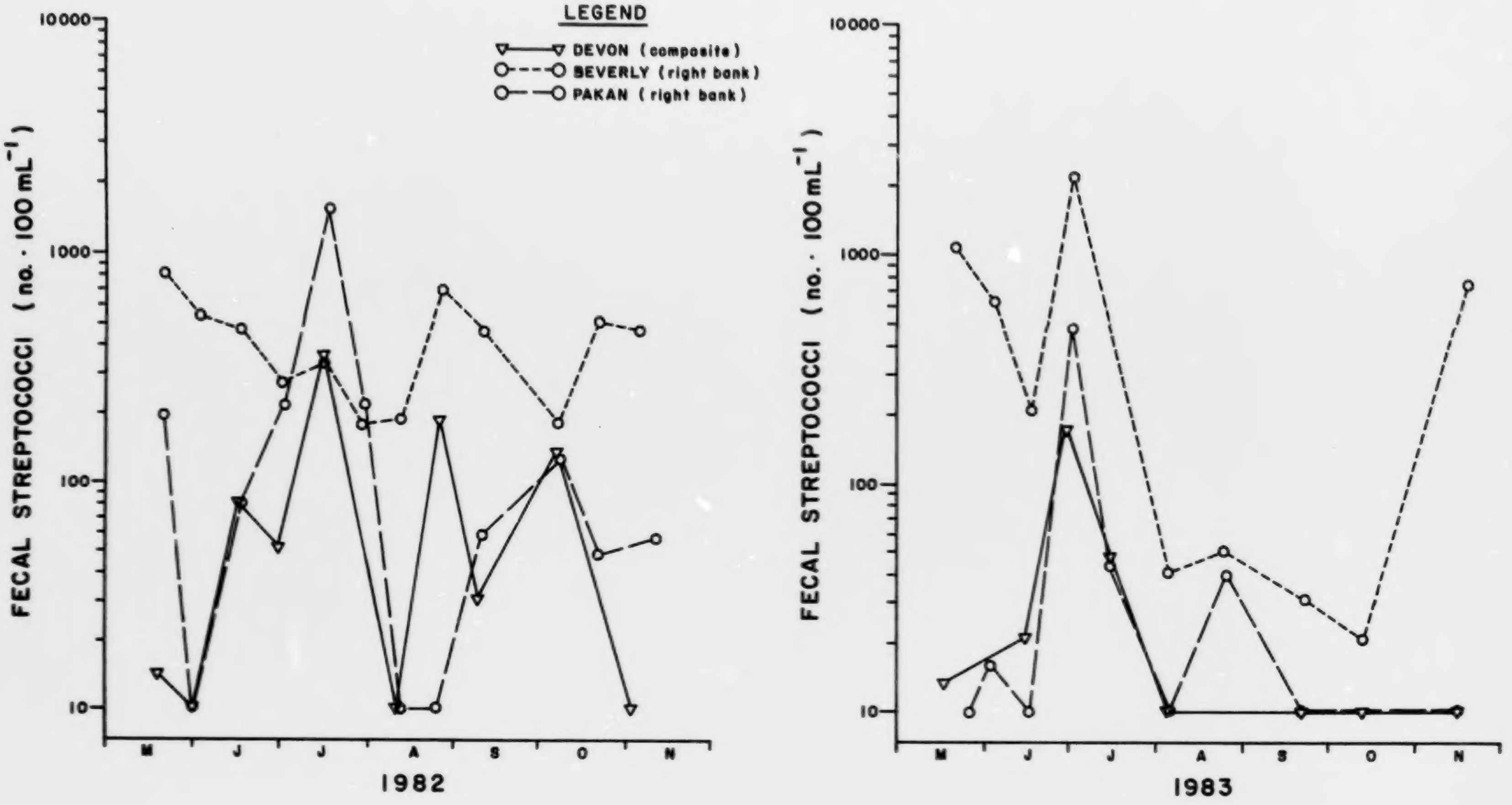

Fig. 14.3 Fecal Streptococci in the N S R at Devon , Beverly bridge and Pakan , 1982 and 1983 .

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discharge came from Calmar via Conjuring Creek and entered the NSR about five river kilometres upstream of the sampling location at Devon. However, the discharge from the Calmar lagoons took place in May and October in 1982 (L. North, pers. comm.). An increase in coliforms might have been expected as a result of the discharge in late October, but this was not the case. Fecal coliforms were less than 10 per 100 mL on October 19 and November 2 at the Devon location, suggesting that this small discharge has little impact on the river.

Counts of indicator bacteria at the Beverly Bridge right-bank site were often two orders of magnitude higher than at Devon. The right-bank site is located within the unmixed plume from the Gold Bar Wastewater Treatment Plant (GBWTP) where high numbers of bacteria would be expected. Counts of indicator bacteria at Beverly Bridge in 1982 were low in July, when heavy rainfall and subsequent high river flow (1100 m^3s^{-1}) diluted the sewage effluent entering the river. As flows declined and subsequent dilution of sewage effluent decreased, numbers of bacteria increased. The 1983 seasonal pattern was characterized by very high values for all indicator bacteria in late June, and very low values in August. The high June counts may be explained by the concentrating effect of relatively high flow from the sewage treatment plant combined with a low flow in the river at that time. The effects of dilution during peak flow in July 1983, which was considerably lower (375 m^3s^{-1}) than the peak flow of the previous year, were not apparent. The somewhat lower counts in August of 1983 than August 1982 may represent natural variation, although temperatures were somewhat higher in August 1983 than in the previous year. Higher water temperatures and light intensity in August are factors that would contribute to higher natural die-off rates among bacteria.

Seasonal fluctuations were more obvious at Pakan than at other sampling locations. Numerical variations are inversely related to the distance from the source (travel time of the river water) and the water temperature. When the water was cool and flows were high, such as in June and early July of both years, indicator bacteria survived in high numbers as far downstream of Edmonton as Pakan. For example, in June 1983 FC counts at the Pakan right-bank site were similar to those at the Beverly Bridge right-bank site (Fig. 14.2). Counts of all indicator bacteria declined rapidly to background levels (i.e. counts at Devon) in late July and August of both years.

Temperature is a major factor in bacterial survival. Geldreich _et_ _al_. (1968) found that at 20°C, only 10% of an original population of FC would remain after 1.5 days (the approximate travel time from Beverly Bridge to Pakan at a flow of 140 $m^3 \cdot s^{-1}$), but at 10°C approximately 65% would remain. Even when flows are high, as in July 1982 (1100 $m^3 \cdot s^{-1}$), FC survival at 20°C would be only 25%, assuming a travel time of one day. Numbers of TC and FS at Pakan increased in fall 1982 when the water temperature declined. In fall 1983, counts of TC increased, but levels of FC and FS remained at background levels.

In general, a large portion of the bacteria entering the river from municipal discharges would be expected to survive as far as Pakan during peak flow in June or July; die-off would only reduce populations to background levels when water temperature were high during late July and August. Bacteria could also reach the Saskatchewan border in considerable numbers in spring and fall when waters are cool, even at low flows. Variations in local precipitation and subsequent surface runoff, and differences in die-off rates among bacteria complicate the interpretation of TC, FC, and FS data gathered during the summer period.

14.2 Results and Discussion: Spatial Trends

The sampling locations for the study were established to assess the impact of the city of Edmonton on the NSR. The bacteria data illustrate this impact particularly well. Figures 14.4 to 14.7 show median values of indicator and heterotrophic bacteria at each location for the study period.

Median counts of indicator bacteria at Devon were very low compared to those at downstream locations. None of the counts in individual samples exceeded 1000 TC/100mL or 200 FC/100mL. For discussion purposes, Devon median values of approximately 50TC/100mL and 10FC/100mL may be considered "natural" or background. These values are somewhat higher than medians calculated from the Alberta Environment River Water Quality Monitoring Network data collected

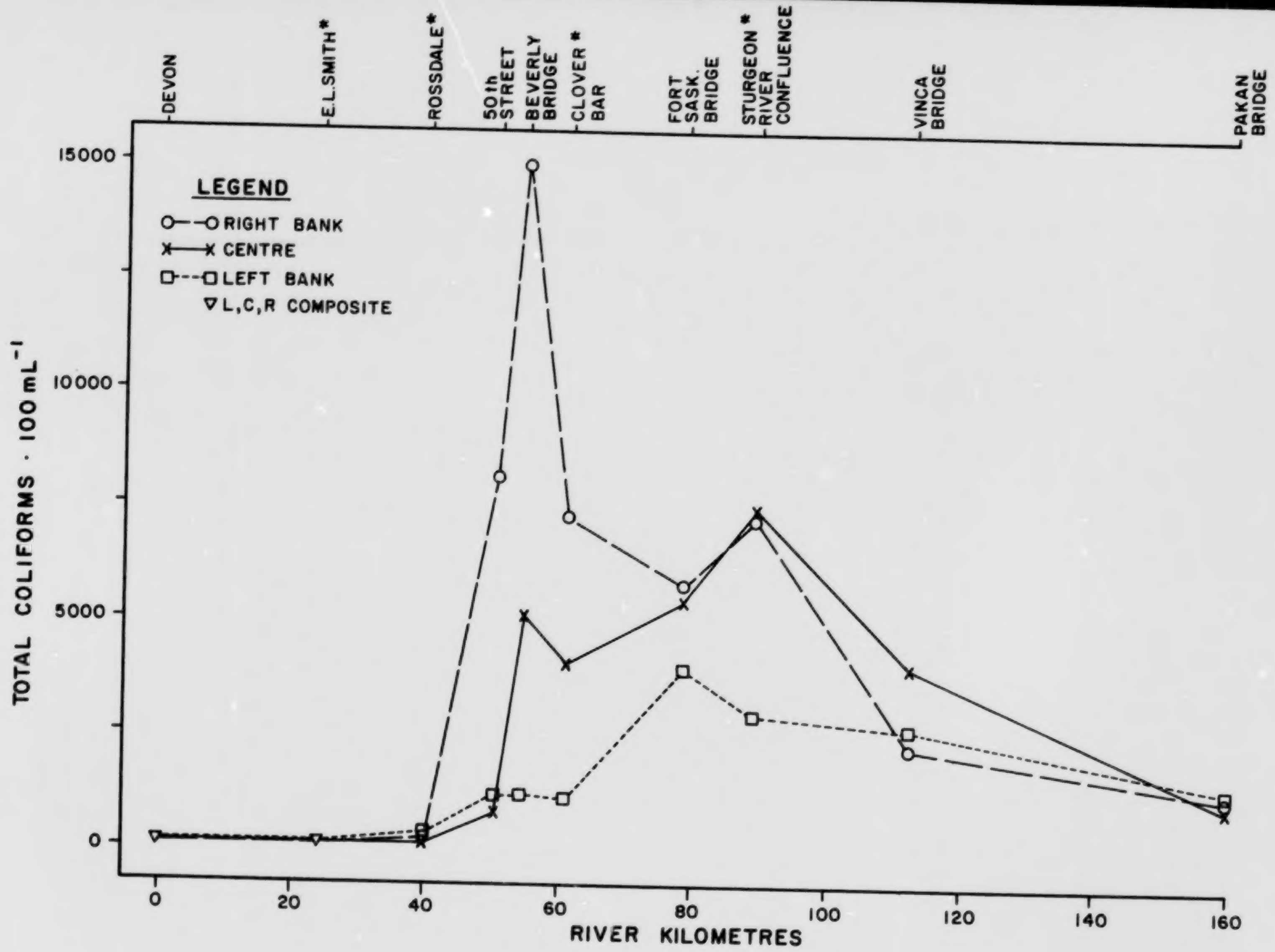

Fig. 14.4 Total Coliforms in the NSR. Median values May - November, 1982 and 1983. (* sampled 1982 only)

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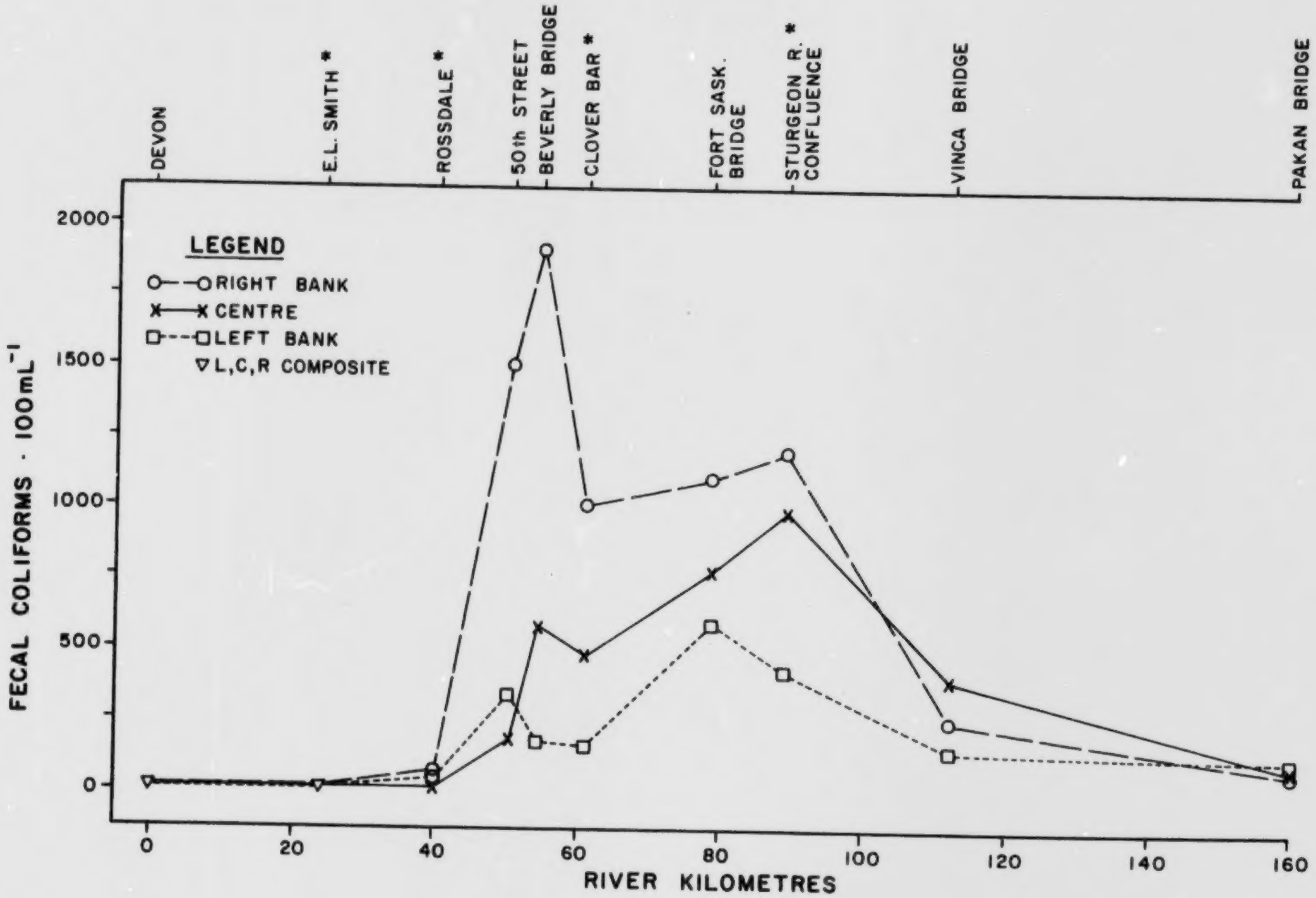

Fig. 14.5 Fecal Coliforms in the NSR. Median values May - November, 1982 and 1983. (* sampled 1982 only)

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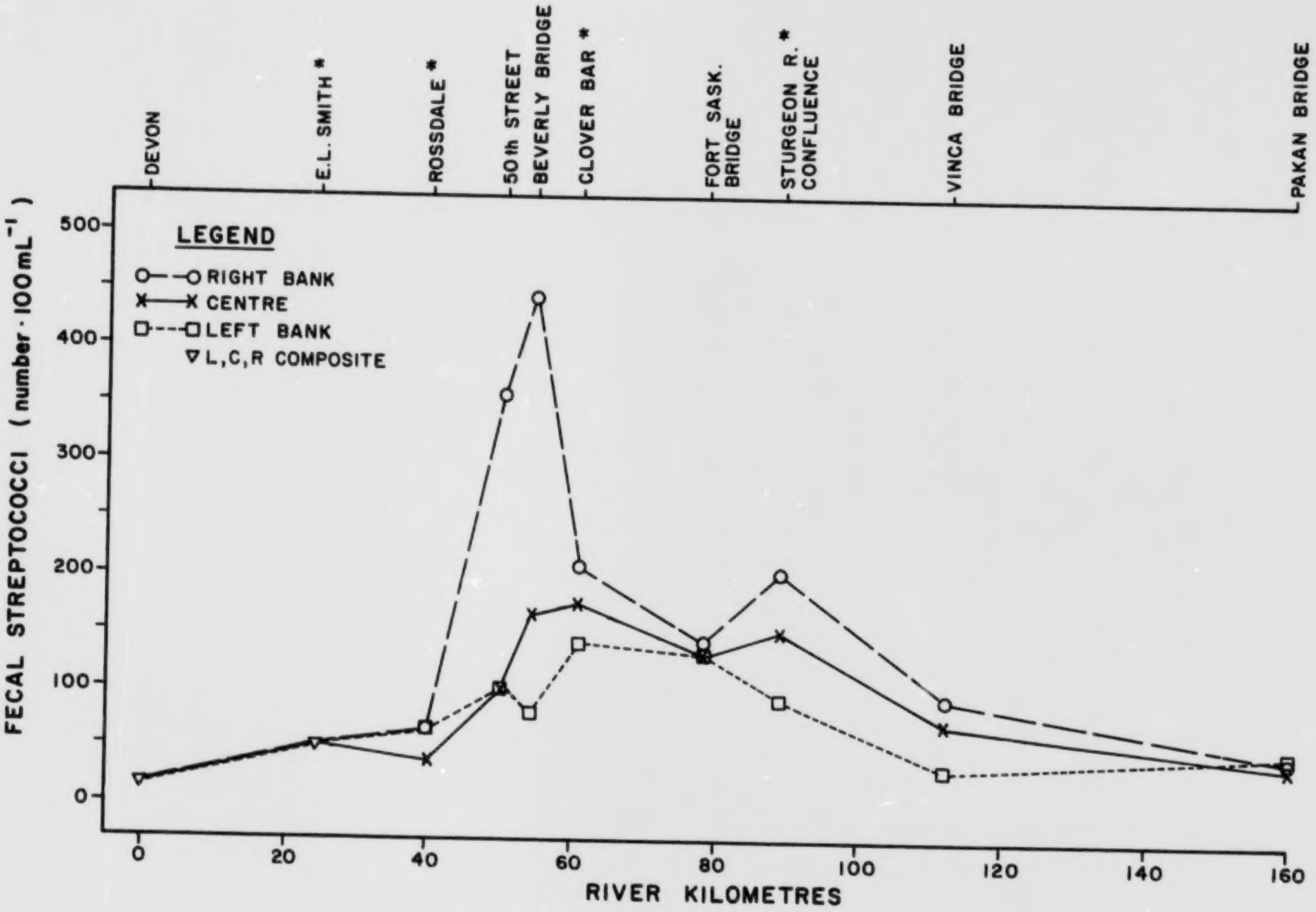

Fig. 14.6 Fecal Streptococci in the NSR. Median values May - November, 1982 and 1983. (* sampled 1982 only)

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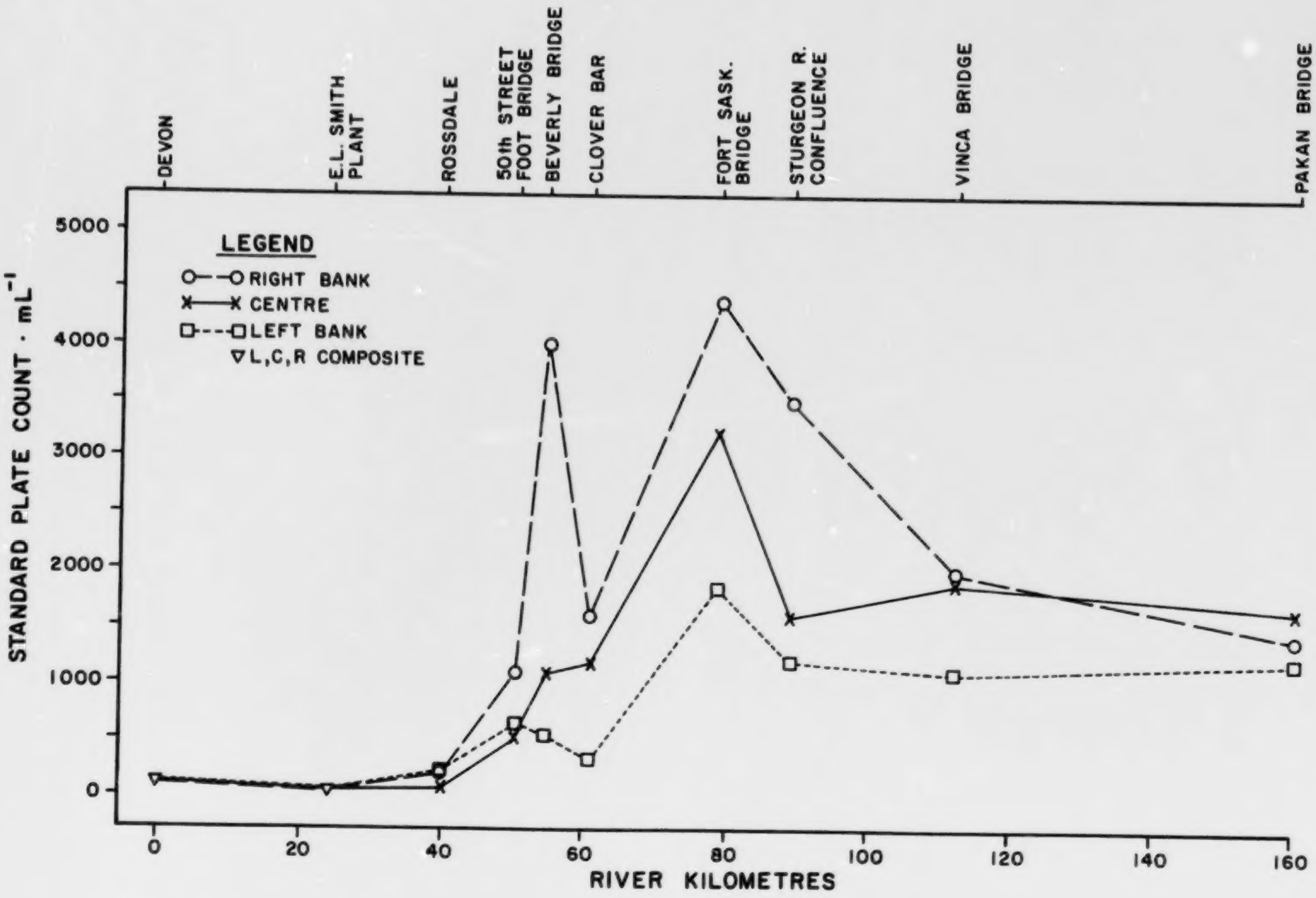

Fig. 14.7 Heterotrophic bacteria in the NSR (Standard Plate Count). Median values May - November , 1982 and 1983.

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monthly at Devon during open water seasons, 1977-1982: 16 TC/100mL, 4 FC/100mL. However, it is likely that the difference between the two data sets represents year-to-year variations rather than a general increase in bacteria in the river at Devon.

The next sampling location downstream, E. L. Smith WTP, was sampled only in 1982. Counts of indicator and heterotrophic bacteria were similar to those at Devon, indicating no major inputs of bacteria between these locations.

Rossdale was the most upstream location sampled within the City of Edmonton and was sampled only in 1982. Counts in the centre of the river were similar to those at upstream locations. However, TC and FC counts from right-bank and left-bank sites were significantly higher than counts at E. L. Smith ($P<0.001$, $n = 11$). There was no significant difference between FS counts in samples from E. L. Smith and Rossdale. Sewage contamination of water in storm runoff seems possible, because the FC:FS ratios in right-bank and left-bank samples at Rossdale were generally higher than those in composite samples from E. L. Smith or centre-channel samples from Rossdale. In 1983, samples collected from Whitemud Creek contained levels of coliforms two to three times the levels measured in the NSR. The FC:FS ratio was greater than 4 in several of the Whitemud samples. Five small municipal effluents entered the Whitemud Creek system south of the city at that time. In addition to Whitemud Creek, five major storm sewers discharge on the right bank and six on the left bank of the

NSR above Rossdale; nineteen smaller storm or combined sewer outfalls are also located upstream of Rossdale (see Section 2.9). These discharges were not sampled during the study.

At 50th Street Footbridge, the next sampling location downstream, counts of indicator and heterotrophic bacteria were markedly higher in 1982 samples, especially in the right-bank samples. At this site, 42% of the samples had counts exceeding 2400 TC/100mL and FC counts were frequently above 200/100mL. FC/FS ratios were greater than 4 in 12 of the 22 right-bank samples from the 50th Street Footbridge location, suggesting human fecal contamination. Because this location was upstream of the GBWTP, potential sources of this contamination were investigated during 1983. Counts of coliforms in samples from the Fulton Creek discharge, which enters the river about 1 km above the 50th Street Footbridge location, were as high as those in sewage effluent (over 24,000/100mL for both TC and FC). It was discovered that raw sewage was leaking into Fulton Creek. This problem was corrected by the City of Edmonton in midsummer, and fecal coliform counts in right-bank samples decreased from 9500/100mL on August 23, 1983, to 80/100mL on September 20, 1983. Indicator bacteria counts in left-bank samples in this vicinity were also quite high; combined sanitary and storm sewers were probably the source.

At the next sampling location, immediately downstream of Beverly Bridge, right-bank samples were collected within the effluent plume of GBWTP. All TC counts in samples from this site exceeded 2400 TC per 100 mL, as did most of the counts from centre-channel samples.

Left-bank FC values at Beverly Bridge were significantly lower than left-bank FC values at 50th Street Footbridge ($P<0.05$, $n = 21$), suggesting die-off or dilution between the upstream source and the Beverly location.

The Clover Bar location, 6 km downstream of the GBWTP outfall, was sampled only in 1982. Median values for indicator and heterotrophic bacteria in right-bank samples were lower than median values from Beverly Bridge right-bank samples, although centre-channel and left-bank values were similar for the two locations. It is likely that the GBWPT outfall plume mixed along the right shore or shifted toward the centre as the river flowed around the large bend between the two sampling locations. In spite of this, TC counts in all 1982 right-bank samples exceeded 2400/100mL and FC counts in all but two of twelve 1982 right-bank samples exceeded 200/100mL.

The Fort Saskatchewan sampling location is approximately 24 km below the GBWTP outfall, and is downstream of both the St. Albert municipal lagoon discharge to the left-bank and the City of Edmonton's Bremner lagoon discharge to the right-bank. These discharges contributed to high levels of indicator and heterotrophic bacteria throughout this part of the NSR. Counts exceeded 2400 TC/100mL in 51 of the 57 samples collected at the three sites at this location. Counts in left-bank samples from Fort Saskatchewan were significantly higher than counts in left-bank samples from Clover Bar ($P< 0.001$, $n=12$).

There was no significant difference between 1982 TC counts at the Fort Saskatchewan location and 1982 TC counts at the location immediately downstream of the Sturgeon River - NSR confluence ($P > 0.05$, $n = 10$, centre-channel sites), even though median values for right-bank and centre-channel sites were somewhat higher at the downstream location. The municipal effluent from Fort Saskatchewan may have affected right-bank and centre-channel samples; left-bank TC values were significantly lower than centre-channel values ($P < 0.005$, $n = 11$). The left-bank sampling site may have been within the Sturgeon River plume, because 1983 samples from the Sturgeon River gave comparatively low coliform counts (1983 range: 12 to 3400 TC per 100 mL, < 2 to 400 FC per 100 mL).

In general, bacterial counts in the NSR declined between the Sturgeon River location and the Vinca Bridge location, probably because of die-off and mixing. The Vinca Bridge location is downstream of the mouths of the Redwater River on the left bank and Beaverhill Creek on the right bank; 1983 samples from these streams gave low counts of indicator bacteria. There was little difference in counts from left-bank, centre-channel and right-bank samples for any of the types of bacteria sampled at Vinca, but a high percentage of samples from this location in 1982 and 1983 gave TC counts greater than 2400 per 100 mL.

At Pakan Bridge, median values for indicator and heterotrophic bacteria were slightly lower than at the locations immediately upstream. However, the median TC values from right-bank, centre-channel and left-bank samples were more than 20 times higher than the median TC values from Devon Bridge samples, and FC numbers were nine times higher than at Devon Bridge. A similar ratio was observed for data from the Alberta Environment River Water Quality Monitoring Network for the May to November period, 1978 to 1982, at Pakan. The differences for both TC and FC numbers between Devon and Pakan were significant for both sets of data (this study data 1982-83, $P< 0.001$, $n = 20$; RWQMN data 1978-82 $P< 0.001$, $n = 25$ for TC, $n = 29$ for FC).

14.3 Surface Water Quality Objectives

In the Alberta Surface Water Quality Objectives (ASWQO), there are two categories of criteria concerning bacteriology in surface waters: one concerns water to be withdrawn for treatment and distribution as a potable supply; the other concerns waters used for direct contact recreation or vegetable crop irrigation (Alberta Environment 1977). The latter criteria are used in this report for two reasons: first, the Objectives for contact recreation and/or vegetable crop irrigation are considerably more stringent than those for water to be withdrawn for treatment prior to distribution for domestic use; second, there are no water withdrawals for domestic use from the impacted portion of the NSR study section. The ASWQO criteria for waters used for recreational purposes are:

> "In waters used for direct contact recreation or vegetable crop irrigation the geometric mean of not less than five samples taken over not more than a 30-day period should not exceed 1,000 per 100 ml total coliforms, nor 200 per 100 ml fecal coliforms, nor exceed these numbers in more than 20 percent of the samples examined during any month, nor exceed 2,400 per 100 ml total coliforms on any day." (p. 5, Alberta Environment 1977)

Drinking water quality standards (e.g. Guidelines for Canadian Drinking Water Quality 1978, Department of National Health and Welfare 1979) apply to water used for human consumption, whether the water is disinfected or not. These standards are much more stringent than surface water quality standards, and the two should not be confused.

The bacterial sampling in this study was not carried out in accordance with all ASWQO criteria, especially the requirement for a minimum of five samples in any consecutive 30-day period. Therefore, only Objectives relevant to single samples can be applied strictly to the results obtained. Results for other bacterial groups, such as fecal coliforms (FC) and fecal streptocci (FS), can be used as a general indication of bacteriological water quality.

Bacterial densities were greater than the ASWQO for direct contact recreation in a high percentage of single samples taken in close proximity to major outfalls which contribute to the unnatural bacterial flora of the NSR (Fig. 14.8). Although the percentage of

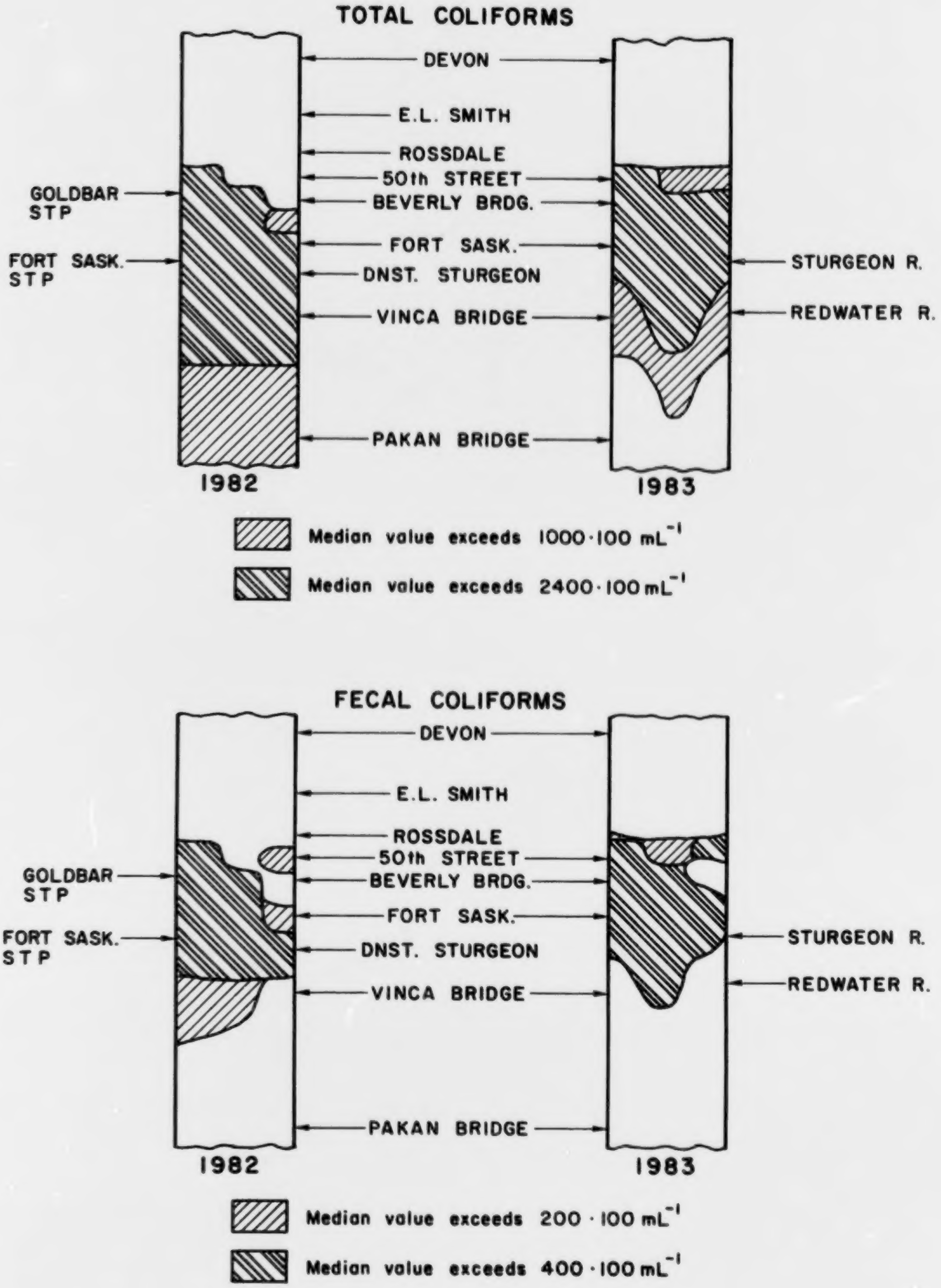
TOTAL COLIFORMS
DEVON
E.L. SMITH
ROSSDALE
50th STREET
BEVERLY BRDG.
FORT SASK.
DNST. STURGEON
VINCA BRIDGE
PAKAN BRIDGE
GOLDBAR STP
FORT SASK. STP
STURGEON R.
REDWATER R.
1982
1983
▨ Median value exceeds 1000·100 mL⁻¹
▧ Median value exceeds 2400·100 mL⁻¹
FECAL COLIFORMS
DEVON
E.L. SMITH
ROSSDALE
50th STREET
BEVERLY BRDG.
FORT SASK.
DNST. STURGEON
VINCA BRIDGE
PAKAN BRIDGE
GOLDBAR STP
FORT SASK. STP
STURGEON R.
REDWATER R.
1982
1983
▨ Median value exceeds 200 · 100 mL⁻¹
▧ Median value exceeds 400 · 100 mL⁻¹

Fig. 14.8 Concentrations of total and fecal coliforms in the North Saskatchewan River.

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samples complying with the criteria increased in downstream direction, the percentage of compliance remained below 80% at Pakan, where the NSR is considered to be mixed.

Table 14.1 is a summary of TC, FC, and FS median values for Devon and Pakan, the most upstream and downstream locations in the study section of the NSR. For comparison, some data from the Alberta Environment River Water Quality Monitoring Network are included. Table 14.1 also provides a summary of values for these two study locations as they compare to ASWQO.

In general, the bacteriological results indicate that the NSR was unsuitable for contact recreation in the impacted section downstream of the City of Edmonton.

14.4 Impacts

The most sensitive potential uses of the NSR are direct contact recreation and vegetable crop irrigation. However, vegetable production using untreated river water is minimal in the watershed. Most microbiological water quality objectives, including the Alberta Surface Water Quality Objectives, are based on the assumption that health risks to swimmers, water skiers, and other participants in direct water contact recreation, are unacceptable when bacterial counts exceed the specified limits. This assumption stems from studies which associate gastrointestinal, nose, and throat illnesses with high levels of TC and FC. Densities of TC and FC usually exceeded ASWQO criteria in the section of the NSR between and

TABLE 14.1 Total and fecal coliforms and fecal streptococci in samples from Devon and Pakan, 1978-1983 median values, May to November, 1978-1983, and comparison with Alberta Surface Water Quality Objectives.

	Devon (n)	Pakan (n)		
RWQMN** 1978-82				
TC	13 (27)	490 (25)		
FC	4 (32)	40 (29)		
FS	8 (18)	30 (19)		
% of samples complying with A.S.W.Q.O.*:	100%	73%		
this study 1982-83	Composite	Left Bank	Centre	Right Bank
TC	56 (21)	1400 (20)	1100 (19)	1300 (21)
FC	10 (21)	105 (20)	96 (19)	88 (21)
FS	18 (21)	45 (20)	39 (19)	42 (21)
% of samples complying with A.S.W.Q.O.*:	100%	36%	79%	71%

* Alberta Surface Water Quality Objectives (Alberta Environment 1977) recommend a maximum of 2400 $TC \cdot 100mL^{-1}$ on any one day for direct contact recreation; not more than 20% of the samples in any month should exceed 1000 TC per 100 mL of sample or 200 FC per 100 mL of sample; there are no ASWQO for FS.

** Alberta Environment River Water Quality Monitoring Network including 50th Street Footbridge, right-bank site, and Vinca Bridge, centre-channel site (Fig. 14.8).

Some attention has been focussed on the recent detection of antibiotic-resistant bacteria in the NSR (Bell 1983). These bacteria contain genetically transferred R plasmids or R factors, which are circles of DNA separate from the bacterial chromosome. A single R factor may determine resistance to several drugs. R factors can be transferred from one bacterium to another within the human gut, and transfers are enhanced when antibiotics are administered, because the gut environment is altered (Gyles 1984). R-factor transfers are not limited to members of a single species or group of bacteria and, therefore, a relatively innocuous species such as Escherichia coli can transfer resistance to a variety of pathogenic genera, such as Salmonella and Shigella. Because large numbers of E. coli occur in humans and their feces, this organism may be an important reservoir for R factors. If E. coli containing R factors is ingested, transfer of drug resistance to the normal gut flora may occur. This resistance can then be transferred to a pathogenic species months or years later, resulting in a disease that is difficult to treat (Grabow et al. 1974).

Transfer of R factors can also occur in feces and in sewage lagoons. In a study of sewage from several Western Canadian cities including Edmonton, Bell et al. (1981) found that about 10% of the fecal coliform population in both raw sewage and sewage plant effluent contained R factors. Final effluent tended to have a slightly higher percentage than raw sewage, suggesting a greater survival rate for drug-resistant forms.

In a study of the NSR, Bell (1983) found that the greatest percentage of drug-resistant fecal coliforms occurred in the Edmonton area; no drug resistant fecal coliforms were found in the headwaters. It is not possible to assess health risks or even the importance of the problem in the NSR from this limited data set. There is no concern with drinking water, because treatment would destroy R-factor bacteria.

Although the subject of R-factors and their importance to human health is still a matter of some controversy, the long-term implications are that the percentage of resistant bacteria entering the river would gradually increase through selective pressure on the bacterial population and continued use of antibiotics. Effluent from hospitals and animal-holding facilities where antibiotics are used likely contribute to the spread of R-factor bacteria. Since indicator bacteria can potentially contribute to the incidence of human disease through R factor transfer, new water quality standards and improved treatment of sewage effluent may be needed (Grabow et al. 1974).

15.0 BIOCHEMICAL AND CHEMICAL OXYGEN DEMAND (BOD/COD)

Surface waters contain various quantities of organic matter in both dissolved and particulate forms. The organic load carried by surface waters may be increased by the addition of municipal and industrial waste effluents. Organic matter is oxidized into stable inorganic compounds by the aerobic microflora in the aquatic environment and by chemical oxidation.

The biochemical oxygen demand (BOD) is a measure of the oxygen consumed in the oxidation of organic material in water by aerobic microbial decomposition under controlled laboratory conditions, providing there are no toxic substances present to interfere with biological activity. The BOD test is commonly used to assess the potential oxygen requirements of waste discharges entering receiving waters. However, the test may be of limited value as a measure of true oxygen demand in surface waters, because the laboratory setting does not duplicate natural stream conditions for such variables as temperature, sunlight, dissolved oxygen concentrations, water movement, and populations of living organisms (American Public Health Association _et al_. 1980).

The chemical oxygen demand (COD) is a measure of the amount of oxygen required for the chemical oxidization (dichromate oxygen consumption) of organic and inorganic matter in water. COD like BOD indicates the potential for organic material to reduce the dissolved oxygen content in water, although there is not necessarily a correlation between the two measures. In surface waters, COD almost always exceeds BOD (McNeely _et al_. 1979).

In 1982, BOD analyses were conducted at the Gold Bar Laboratory, City of Edmonton (detection limit 0.3 $mg \cdot L^{-1}$); in 1983, BOD analyses were conducted at the AEC laboratory, Vegreville (detection limit 1.0 $mg \cdot L^{-1}$). COD determinations were conducted at AEC in both 1982 and 1983. Additional details concerning these methods are referenced in the general methods section.

15.1 Results and Discussion: BOD

Both seasonal and spatial variations were evident in the BOD levels determined within the NSR study section. A spatial analysis (Fig. 15.1) shows that for upstream locations (Devon to the 50th Street Footbridge sites) median BOD values were low, ranging from less than 1.0 $mg \cdot L^{-1}$ to 1.3 $mg \cdot L^{-1}$. A sharp increase in BOD occurred at the Beverly Bridge right-bank site (median = 2.2 $mg \cdot L^{-1}$) and right-bank sites as far downstream as Pakan remained at similar levels (medians from 1.5 to 2.2 $mg \cdot L^{-1}$). Except for a marked increase in BOD at the Rundle Footbridge left-bank site (1.6 $mg \cdot ^{-1}$), left-bank sites were near 1.0 $mg \cdot L^{-1}$ as far downstream as Cloverbar, below which BOD increased in downstream direction, reaching concentrations of 2.0 $mg \cdot L^{-1}$ at both Vinca and Pakan.

Seasonal variations in BOD concentrations are presented graphically in Fig. 15.2. At most sites and on most occasions, the highest BOD values were recorded either in spring (May to early June) or in late fall or winter. BOD values in the summer period were usually at their lowest. Exceptions to the lower summer values

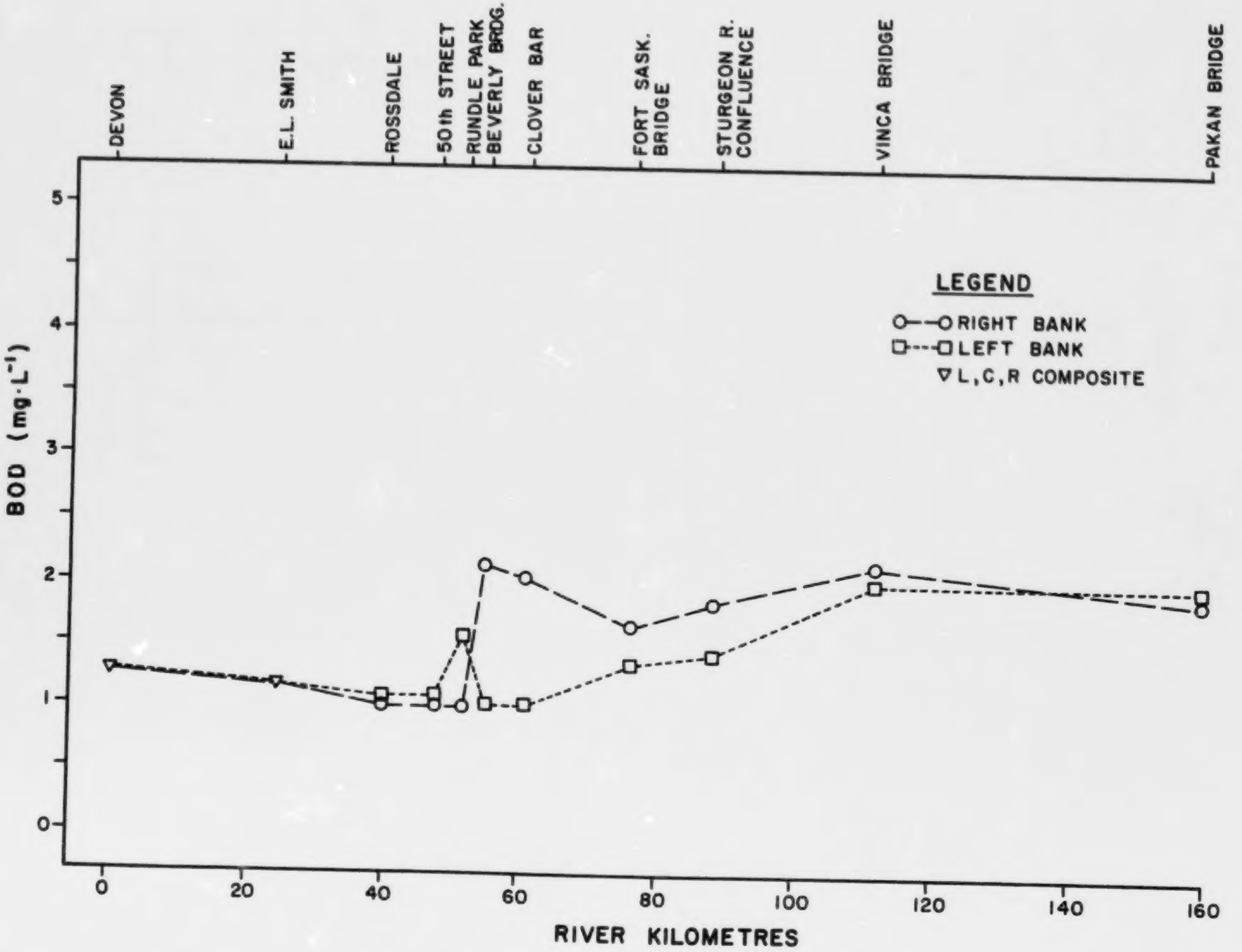

Fig. 15.1 Spatial biochemical oxygen demand (BOD), median values, NSR, 1982-1983.

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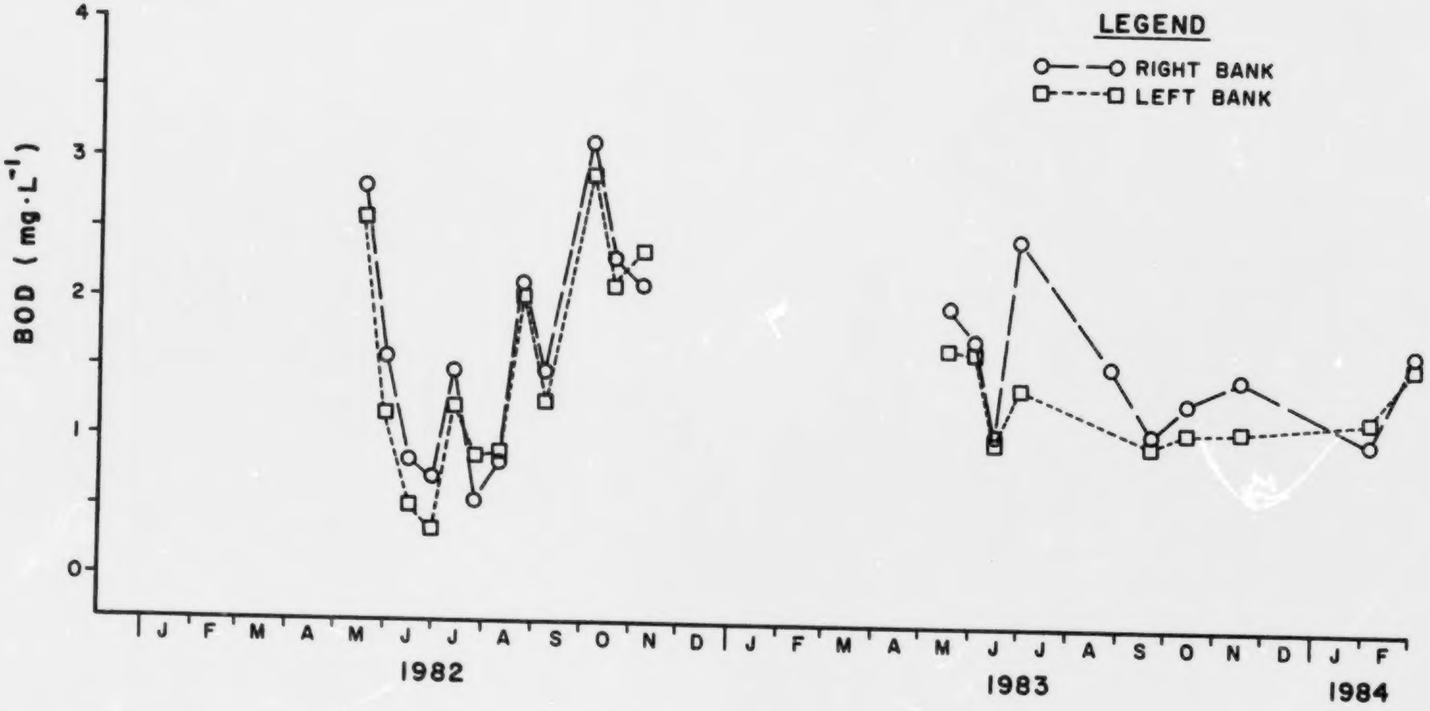

Fig. 15.2 Seasonal biochemical oxygen demand (BOD), median values, NSR, 1982-1983.

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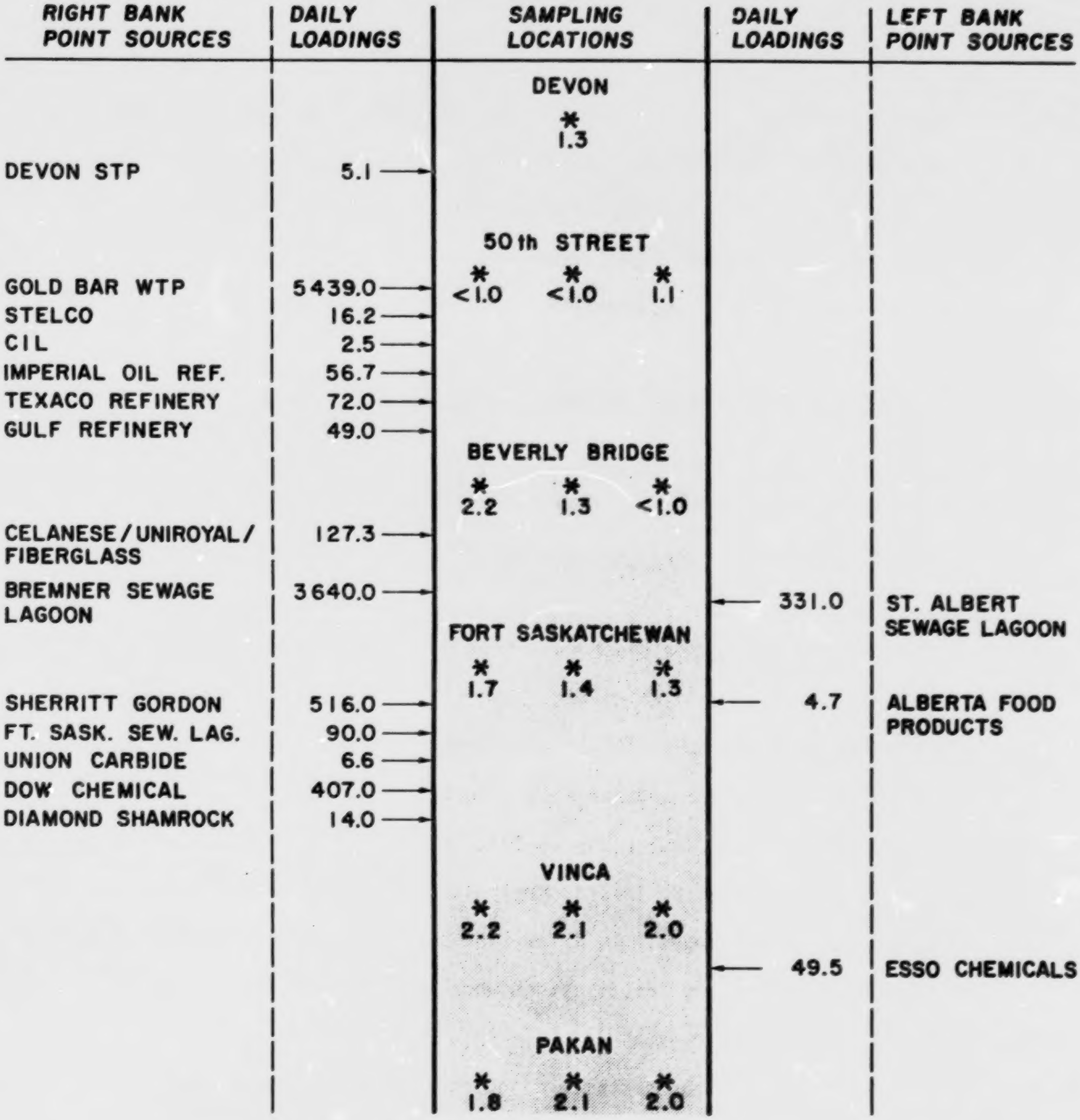
occurred on July 13, 1982 and June 28, 1983, when sampling coincided with the high-flow period of each year and when substantial BOD loading from tributaries was recorded. Loading contributions to BOD ($kg \cdot d^{-1}$) from the four major tributaries entering the study section of the NSR for two sampling events in 1983 are tabled below:

	Whitemud	Redwater	Beaverhill	Sturgeon	Total
June 28-29/83	5661.	1865.	7872.	3932.	19330.
Sept.20-21/83	6.	20.	1.	69.	96.

Continuous point-source discharges from municipal and industrial facilities contributed an average load of approximately 10,825 $kg \cdot d^{-1}$, 88% of which was from municipal discharges of treated sewage, and only 12% of which was from industrial discharges. Therefore, during a high-flow period in 1983 (June 28-29), tributary contributions were approximately 1.8 times as great as were the above continuous point-source discharges. In a low-flow period (Sept.20-21), on the other hand, tributary contributions were less than 1% of continuous point-source discharges.

Based on continuous-source discharges, the right-bank sites from 50th Street Footbridge to Vinca received 96% of total BOD loading (Fig. 15.3), which was consistent with the higher right-bank site median values measured from Beverly Bridge to Vinca. Statistical comparisons between Devon, the upstream location, and all other sites


RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
* 1.3
DEVON STP 5.1
50th STREET
* <1.0 * <1.0 * 1.1
GOLD BAR WTP 5439.0
STELCO 16.2
CIL 2.5
IMPERIAL OIL REF. 56.7
TEXACO REFINERY 72.0
GULF REFINERY 49.0
BEVERLY BRIDGE
* 2.2 * 1.3 * <1.0
CELANESE / UNIROYAL / FIBERGLASS 127.3
BREMNER SEWAGE LAGOON 3640.0
331.0 ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
* 1.7 * 1.4 * 1.3
SHERRITT GORDON 516.0
4.7 ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG. 90.0
UNION CARBIDE 6.6
DOW CHEMICAL 407.0
DIAMOND SHAMROCK 14.0
VINCA
* 2.2 * 2.1 * 2.0
49.5 ESSO CHEMICALS
PAKAN
* 1.8 * 2.1 * 2.0

TOTAL INDUSTRIAL LOAD = 1321.5
TOTAL MUNICIPAL LOAD = 9505.1
TOTAL DAILY LOAD = 10826.6

Fig. 15.3 Diagrammatic representation of 1982-84 median BOD concentrations ($mg \cdot L^{-1}$) and estimated municipal and industrial point source loadings ($kg \cdot d^{-1}$) .

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sampled during the study period show that Beverly Bridge right-bank, Vinca left-bank, centre-channel and right-bank, and Pakan left-bank sites had significantly higher BOD values than Devon ($P<.05$, $n = 19$, 19, 15, 19 & 14, respectively). Fort Saskatchewan left-bank, centre-channel, and right-bank sites and Pakan centre-channel and right-bank sites were not significantly different from Devon ($P<.05$, $n = 14$, 13, 13, 16 & 18, respectively). The BOD values for 50th Street Footbridge centre-channel and right-bank sites and Beverly Bridge left-bank sites were significantly lower than Devon ($P<.05$, $n = 16$, 18, 15, respectively); many of the very low values are near the detection limit, and no special importance should be attached to the low BOD values at these three sites.

15.2 Surface Water Quality Objectives: BOD

The Alberta Surface Water Quality Objectives (Alberta Environment 1977) suggest that BOD must not exceed a limit which would create a dissolved oxygen content in receiving waters of less than 5 $mg \cdot L^{-1}$. No specific Canadian guidelines for BOD have been proposed. Waters with BOD levels below 4 $mg \cdot L^{-1}$ are considered reasonably clean, whereas waters with levels greater than 10 $mg \cdot L^{-1}$ are considered polluted (McNeely et al. 1979). In the publication "Quality Objectives for Aquatic Life in European Fresh Waters", Baudo et al. (1978) recommend a "highest quality objective" of 5 $mg \cdot L^{-1}$ or less, and a minimum quality objective of 8 $mg \cdot L^{-1}$.

Of 461 BOD tests done on NSR water in this study, 439 (or 95.2%) were less than 4 mg•L^{-1}; none exceeded 10 mg•L^{-1}. At the upstream locations from Devon to Rundle Footbridge and the Beverly Bridge left-bank and centre-channel sites, BOD values were at all times less than 4.0 mg•L^{-1}. The small number of BODs which were over 4.0 mg•L^{-1} occurred primarily at right-bank sites from Beverly Bridge to Pakan. At Pakan, 51 of 55 tests (92.7%) were under 4.0 mg•L^{-1}. The few high BOD values occurred either in the spring (May) or late fall and winter (Oct., Nov., Feb.).

15.3 Results and Discussion: COD

COD values showed less spatial variation than BOD values (Fig. 15.4). Except for the Sturgeon River (9) left-bank site (median = 24 mg•L^{-1}), which was sampled in the NSR immediately below the confluence with the Sturgeon River, median COD values ranged from 9.0 to 16.5 mg•L^{-1}. Statistical comparisons between Devon and all other locations except Sturgeon River sampled over the entire 1982-84 period showed no significant differences between sites ($P<.05$, $n = 20$).

Seasonally, the highest COD values usually occurred during high flow periods. Municipal discharges of treated sewage makeup 83% of COD loading from continuous sources, and industrial discharges makeup the remaining 17% (Fig. 15.5).

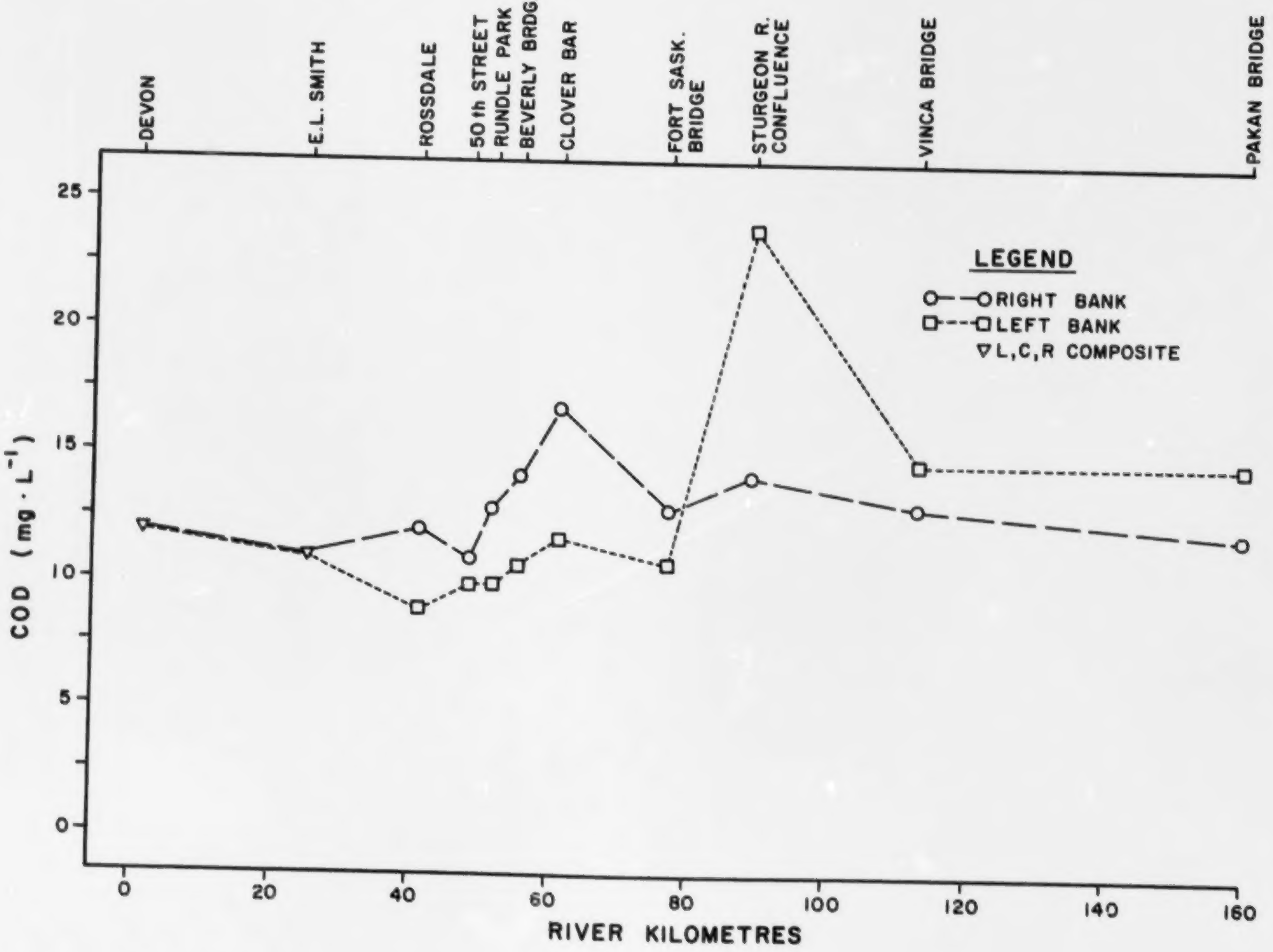

Fig. 15.4 Spatial chemical oxygen demand (COD) , median values , NSR , 1982-1983 .

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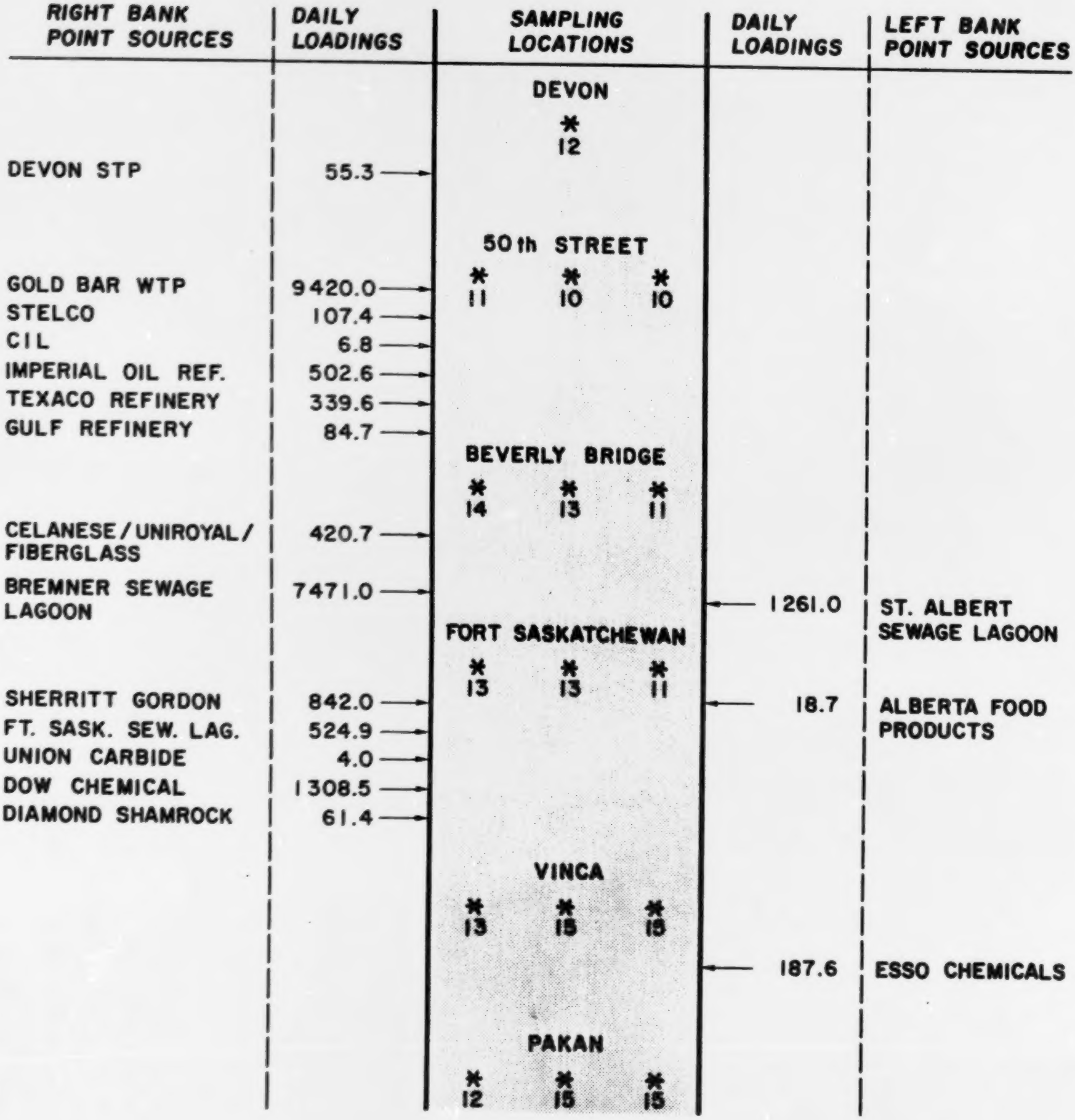
RIGHT BANK POINT SOURCES
DAILY LOADINGS
SAMPLING LOCATIONS
DAILY LOADINGS
LEFT BANK POINT SOURCES
DEVON
12
DEVON STP
55.3
50th STREET
11
10
10
GOLD BAR WTP
9420.0
STELCO
107.4
CIL
6.8
IMPERIAL OIL REF.
502.6
TEXACO REFINERY
339.6
GULF REFINERY
84.7
BEVERLY BRIDGE
14
13
11
CELANESE/UNIROYAL/FIBERGLASS
420.7
BREMNER SEWAGE LAGOON
7471.0
1261.0
ST. ALBERT SEWAGE LAGOON
FORT SASKATCHEWAN
13
13
11
SHERRITT GORDON
842.0
18.7
ALBERTA FOOD PRODUCTS
FT. SASK. SEW. LAG.
524.9
UNION CARBIDE
4.0
DOW CHEMICAL
1308.5
DIAMOND SHAMROCK
61.4
VINCA
13
15
15
187.6
ESSO CHEMICALS
PAKAN
12
15
15

TOTAL INDUSTRIAL LOAD = 3884.0
TOTAL MUNICIPAL LOAD = 18732.2
TOTAL DAILY LOAD = 22616.2

Fig. 15.5 Diagrammatic representation of 1982-84 median COD concentrations (mg·L⁻¹) and estimated municipal and industrial point source loadings (kg·d⁻¹).

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15.4 Surface Water Quality Objectives: COD

No Canadian water quality guidelines for COD have been proposed. In "Quality Objectives for Aquatic Life in European Fresh Waters" (Baudo et al. 1978), a maximum quality objective equal to or less than 10 mg•L and a minimum quality objective equal to or less than 30 mg•L^{-1} is prescribed. The former objective implies a standard compatible with negligible human influence on the ecosystem; the latter refers to the minimum standard necessary to maintain a self-sufficient microbial flora capable of the aerobic decomposition of organic material present in the water.

Not surprisingly, the COD in the NSR fell short of the maximum quality objective. However, COD values rarely approached the minimum objective, and then only in outfall areas (e.g. near confluence with the Sturgeon River). In the downstream parts of the study section of the NSR (e.g. Vinca or Pakan), where mixing is nearly or totally complete, median COD values were well below the minimum objective.

15.5 Impacts: BOD and COD

Most of the year and throughout most of the study section of the NSR, BOD and COD levels indicated a low to moderate organic load in the river. These levels, together with the dissolved oxygen levels actually recorded, indicate that the impact of the organic load on the biotic community is low to moderate.

At certain times of year (mainly for COD during high flows) or in certain river sections receiving large effluent volumes (mainly for BOD), elevated BOD and COD levels were indicative of higher oxygen consumption for the oxidation or decomposition of the organic materials carried by the NSR. It is at these times or places where higher organic loads in future could have a negative impact. Reductions in tributary BOD and COD contributions to the NSR during periods of high flow should result from the completion of the Capital Region Sewage Treatment Plant and the Southeast Regional Trunk Sewer (see Section 2.10).

High BOD or COD levels within prescribed limits could have incipient negative effects when combined with the effects of other variables also approaching surface water quality objective limits. However, little information is available on the synergistic effects of several variables under a variety of climatic and flow conditions.

16.0 SUMMARY

The following summary highlights the major findings and most salient features of the various sections of the report. The appropriate sections of the report are cross-referenced by number for the reader's convenience.

Purpose and Scope (Sections 1.0, 4.0)

A study of the section of the North Saskatchewan River impacted by the greater Edmonton metropolitan area was undertaken in 1982 and 1983 for the purpose of characterizing this section of the river chemically and biologically, assessing certain variables against the Alberta Surface Water Quality Objectives, and appraising actual and potential impacts from pollutants entering this section of the river.

The main emphasis in similar studies has been on water chemistry, which is of limited interpretive value. For instance, the chemistry of flowing water tends to represent a momentary situation and does not reflect either the synergistic effects of two or more variables, or the cumulative effects of variables over a considerable period of time. In the present study, therefore, considerable attention was paid to certain biological components, especially those which act as integrators of environmental conditions.

Sites were selected throughout the study section to represent the relatively unimpacted upstream conditions, the fairly well mixed downstream portion which begins to show some evidence of "recovery", and intermediate sites which would reflect known or suspected sources of impact.

Flows (Section 2.4)

This study was planned to span a minimum of two years, because no one year is likely to be completely representative of normal conditions. Total annual discharge in 1982 was much greater than the historical average, but most of this was due to flows greater than twice normal in July; flows during the other months were near or sometimes below normal. Total annual discharge in 1983 was somewhat below normal; flows were below normal for all months from May to October, inclusive, especially for June and July.

Mixing (Section 3.0)

No new investigation of mixing in the North Saskatchewan River was carried out during this study. A review of existing data indicates poor mixing for at least 70 km downstream of Edmonton (i.e. to Vinca). Previous studies and data from the present report indicate that mixing is probably fairly complete most of the year at Pakan, the most downstream study location.

Temperature (Section 6.0)

North Saskatchewan River water temperatures in the study section ranged from 0°C in winter to about 25°C in summer. The mean increase in water temperature between Devon and Pakan (the most upstream and most downstream locations in this study) for all study dates was less than 1°C. Within the plumes from heated effluent sources, temperature differences can be somewhat greater, as indicated by the open-water stretches in the study section in winter. However, site-to-site differences after some mixing had occurred were below the ASWQO of 3°C rise. This temperature difference in itself is seen to have a more positive than negative impact (e.g. would enhance aeration in winter). Other potential synergistic effects are discussed below.

Dissolved Oxygen (Section 7.0)

During most of the year, dissolved oxygen was near or above saturation levels throughout the study section of the North Saskatchewan River. In general, variations in dissolved oxygen were seasonal rather than spatial. Lowest levels, from about 65% to 85% saturation, were noted at two different times of year - midwinter (February) and midsummer (July). There were seldom significant differences in site-to-site or bank-to-bank values. At all times during this study, dissolved oxygen complied with the ASWQO of a minimum of 5 $mg \cdot L^{-1}$. There were no apparent direct impacts due to the somewhat lower midwinter and summer dissolved oxygen levels. Potential synergistic effects are discussed below.

Major Ions (Section 8.0)

Concentrations of major ions were usually lowest during high-flow periods in the North Saskatchewan River (especially during spring and early summer runoff periods) and highest during low-flow periods (especially in August, but also in mid-winter). For non-filterable residue, the reverse relationship usually prevailed: non-filterable residue was generally higher during high-flow periods and lower during low-flow periods.

There was no change in the pattern of ionic dominance from Devon to Pakan, although there was a slight increase (<10%) in the concentration of most ions in downstream direction. The exceptions were sodium, chloride, and potassium ions, which all had significantly higher concentrations at Pakan.

An analysis of concentrations at various sites and loading by tributaries and effluents showed that municipal discharges were the main source of sodium and chloride loads, with tributaries contributing relatively more sodium than chloride to the loads, and industrial sources contributing about 18% of the median sodium load and about 29% of the median chloride load. For potassium, the largest contribution came from tributaries, considerably less from municipal sources, and only about 3% from industrial sources.

There are no ASWQO for most major ions included in this study. This is partly because concentrations of these ions are extremely variable in natural waters, and partly because they are usually considered harmless, even at much higher concentrations than occur naturally in most Alberta surface waters.

The ASWQO for non-filterable residue is difficult to apply to a river in a developed basin. However, on the basis of upstream-downstream comparisons, the objective was exceeded in nearly 25% of the samples collected during the study period. Most of these exceedences occurred during high runoff periods and seem to have storm sewers as their principal source.

No impacts are believed attributable to changes in major ion concentration throughout the study section of the North Saskatchewan River. The main impacts of elevated levels of non-filterable residue are likely to be on the biota as a result of increased turbidity and associated reduction in light penetration, of habitat fouling through increased sedimentation, and of scouring enhancement during periods of high water.

Metals (Section 9.0)

Of the sixteen metals for which analyses were performed, six (including mercury) were consistently below the detection level throughout the study. Four metals were consistently above the analytical detection limit but showed little seasonal or spatial variation; all were below the limits prescribed by the ASWQO. Iron and aluminum were well above detection levels and their occurrence is linked to seasonal events (i.e. high concentrations at high river flows). Nickel and lead were also present well above detection limits and the pattern of occurrence was spatial, implying point sources. Changes in zinc concentrations were rather sporadic, although there was some evidence of spatial change. Manganese, also present well above the detection level, showed both seasonal and spatial changes, suggesting links to both natural occurrence and point sources.

The natural levels of three metals (iron, manganese, zinc) approached or exceeded the ASWQO. However, none is considered a health hazard at the levels determined in this study. There are no Objectives for aluminum and nickel, but again, neither is considered a health hazard at the levels determined. The source of aluminum is natural; nickel occurrence was linked to industrial discharge. Lead values occasionally exceeded the ASWQO, usually in unmixed sections of the river, and the source of the lead was linked to storm sewers. The principal source is probably automobile emissions, and the lead enters the storm sewers via urban surface runoff.

No identifiable impacts have been associated with metals at the levels detected in the study section of the North Saskatchewan River in 1982 and 1983.

Organics (Section 10.0)

No detectable levels of chlorinated pesticides, chlorinated herbicides, organophosphorus or organonitrogen compounds, or PCB's were found in the North Saskatchewan River samples in this study. The occurrence of acid and base/neutral fractions and purgeable priority pollutants near or below the analytic detection limit suggests that these compounds are not an imminent threat to water users. No surface water quality standards have yet been set for the latter group of compounds.

The concentration of total phenolic compounds in North Saskatchewan River samples only rarely exceeded the ASWQO of 0.005 $mg \cdot L^{-1}$. Of the few high values, most were in unmixed sections of the North Saskatchewan River below point sources. Some phenolic compounds are likely of natural origin, but much of the total concentration undoubtedly derives from municipal and industrial point sources in the Edmonton region. At the levels detected, it is likely that the greatest impact of phenolics would be organoleptic (i.e. affecting taste and odor).

Most other organics identified occurred at very low concentrations and in no clear pattern. Surface water quality standards have not been set for most of these compounds. For others, there were occasional exceedences, but most of these were isolated occurrences.

Nutrients (Section 11.0)

Total phosphorus in the North Saskatchewan River varied both seasonally and spatially. Seasonal high concentrations were associated with peak flows, when most of the total phosphorus was in the particulate form and was unlikely to be available to plants for growth. Higher total phosphorus values downstream than upstream were attributable to point-source discharges, primarily municipal wastewater treatment plants on the right bank. Much of the elevated total phosphorus load at downstream locations was in a biologically available form.

The ASWQO for total phosphorus were exceeded in 85% to 95% of the downstream samples during this study, both in mixed and unmixed sections of the North Saskatchewan River. The much lower fraction (20%) of exceedences at the upstream locations occurred during high-flow periods and was due primarily to naturally occurring biologically unavailable phosphorus.

No toxic or organoleptic effects can be attributed directly to the levels of total phosphorus occurring in the NSR. Because a considerable fraction of the total phosphorus downstream of Edmonton was in the biologically available form, plant growth has been enhanced. During the study period, this growth was mainly in the form of epilithic and other attached algae.

No clear seasonal pattern for total nitrogen in the mainstream NSR was evident. In general, upstream locations showed rather low concentrations of all forms of nitrogen. However, elevated levels of total nitrogen occurred in certain tributaries during runoff periods, especially during June and July. The spatial pattern for total nitrogen was similar to that for total phosphorus: high levels of total nitrogen entering the NSR on the right bank between 50th Street Footbridge and Vinca Bridge produced median concentrations at downstream locations three to five times higher than those at upstream locations.

The ASWQO for total nitrogen were exceeded in 24% of the samples in 1983, mainly from right-bank sites within Edmonton City limits and at downstream locations. Most of the load contributing to these exceedences comes from municipal wastewater treatment plant effluents in the greater Edmonton area.

No toxic or organoleptic effects can be attributed directly to the levels of total nitrogen which occurred in the NSR. However, the levels determined were well above those limiting plant growth. When neither nitrogen nor phosphorus is limiting in rivers, excessive algal development can be expected to occur.

Given the appropriate combination of factors, extensive macrophyte development could occur at the nutrient levels determined for the NSR. This is discussed at greater length below.

Chlorophyll-a (Section 12.0)

Potamo-phytoplankton chlorophyll-a is a measure of the biomass of the "planktonic" algae in the river; epilithic chlorophyll-a is a measure of the biomass of attached algae. Both planktonic and epilithic chlorophyll-a increased significantly in the NSR below major nutrient sources within and downstream of the City of Edmonton. Prior to the conclusion of this study, neither planktonic nor epilithic algae had reached levels causing major concern. However, it is likely that enhanced algal growth and the nuisance factors associated with it could result from any increase in nutrients in future, or from a continuation of current nutrient levels in combination with certain other conditions, such as increased clarity and reduced scouring, which could occur if spring runoff peaks and summer flows were much lower than normal. No surface water quality objectives have been set for chlorophyll-a.

Carbon (Section 13.0)

Values for dissolved inorganic carbon showed no clear spatial or temporal patterns in the study section of the NSR; these values were virtually unaffected by municipal, industrial, or tributary inputs. Although there are no ASWQO for dissolved inorganic carbon, the levels determined in this study fell well within the limits set out by other major drinking and surface water quality guidelines.

Highest total organic carbon values tended to occur when river flows were highest; the particulate organic load was associated with surface runoff, much of which was upstream of the study area, whereas the dissolved fraction was clearly associated with municipal and industrial discharges and tributaries. Dissolved organic carbon values were highest at right-bank sites beginning downstream of the Gold Bar Wastewater Treatment Plant. There was no clear relationship between particulate carbon and discharges from municipal or industrial facilities. However, total organic carbon values were nearly twice as high at Vinca Bridge as at the 50th Street Footbridge, indicating considerable organic enrichment. There are no ASWQO for organic carbon.

Total organic carbon loads have a direct impact on the biochemical oxygen demand (BOD) of surface waters. Particulate organic matter, usually high in organic carbon, serves as food for bacteria and for many invertebrate species. Both groups of organisms tend to increase in numbers in direct response to elevated levels of particulate organic matter.

Bacteria (Section 14.0)

In general, numbers of bacteria in the NSR tended to decline as a result of dilution during high flow periods. Although the reverse relationship occurred at Devon, total numbers of bacteria were usually much lower at this upstream location. Below the Gold Bar Wastewater Treatment Plant, especially on the right bank, total coliforms, fecal coliforms, fecal streptococci, and heterotrophic bacteria counts increased by as much as two orders of magnitude over Devon levels. The counts for most bacterial forms tended to remain high or even to increase as additional effluents from wastewater treatment plants entered the NSR between Gold Bar and Fort Saskatchewan. During the warmest time of year, there was an obvious die-off effect at the most downstream location, although total numbers of bacteria were still high. Because of mixing and natural die-off, both total numbers and bank-to-bank differences tended to decline at Pakan, the most downstream study location.

Total coliform and fecal coliform counts at Devon complied with the ASWQO for direct contact recreation. Although 65% to 79% of all samples complied with the Objectives at Pakan, exceedences were 100% in close proximity to major wastewater treatment plant outfalls.

Biochemical and Chemical Oxygen Demand (Section 15.0)

If median biochemical oxygen demand (BOD) values are considered, there is an approximate doubling of loading between Devon and Pakan, with most of the increase attributable to right-bank discharges from municipal wastewater treatment plants from the 50th Street Footbridge to Fort Saskatchewan. The seasonal patterns of biochemical oxygen demand were different in the two study years: in 1982, there was a spring peak, an early summer decline due largely to dilution, and a late summer and early fall increase; in 1983, early summer peak flows were much below normal, and biochemical oxygen demand values remained fairly constant throughout the year. Winter values were moderately high both years.

ASWQO state that the biochemical oxygen demand must not exceed a level which would result in a dissolved oxygen concentration of less than 5 $mg \cdot L^{-1}$. Dissolved oxygen was never measured at less than 5 $mg \cdot L^{-1}$ during the course of this study. Other standards suggest that biochemical oxygen demand values under 4 $mg \cdot L^{-1}$ are indicative of clean water, whereas values over 10 $mg \cdot L^{-1}$ are indicative of polluted waters. In this study, fewer than 5% of all biochemical oxygen demand samples exceeded 4 $mg \cdot L^{-1}$ and none exceeded 10 $mg \cdot L^{-1}$.

Chemical oxygen demand (COD) values were usually highest during high flow periods, suggesting that much of the chemical oxygen demand was associated with surface runoff or had natural sources. Of that part of the chemical oxygen demand load attributable to continuous point sources, 83% came from wastewater treatment plant effluents.

There are no ASWQO or other Canadian water quality guidelines for chemical oxygen demand. A comparison with other available objectives showed that the North Saskatchewan River fell short of maximum objectives (i.e. near pristine conditions), but only rarely approached minimum objectives (i.e. minimum conditions permitting the survival of a microbial flora capable of decomposing organic matter aerobically).

Zoobenthos (This part of the Summary refers to the material presented in Part Two of this report. It is included here for the reader's convenience).

A study of the water quality of the NSR as reflected by the zoobenthos or benthic invertebrates was initiated in the spring of 1982. Its primary objectives were the characterization of the river as it passes through the Edmonton area, and the identification of the degree of impact from urban development. Another objective was to evaluate complementary zoobenthic studies as integrators of water quality and as aids to the interpretation of chemical and physical data. Benthic invertebrate samples were collected in spring, summer, and fall 1982 at 11 locations from Devon to Pakan for both left-bank and right-bank sites.

The results of multivariate analyses (cluster and principal component analyses) and an evaluation of commonly used community parameters (total numbers, Shannon-Wiener diversity, distribution of numbers among taxa at each site, and distribution of numbers among sites for each major taxon) led to the identification of three major groups of sites. These groups represent zones of different water quality in the river.

Zone I was a group of sites which were located upstream of major point-source effluents. Benthic invertebrates were virtually unimpacted and the invertebrate assemblage was indicative of river water of high quality. The zoobenthos was characterized by relatively low total numbers and by high values for the Shannon-Wiener diversity. Taxa such as Ephemeroptera, Plecoptera, and Trichoptera (known to be intolerant of high organic loads), were as important numerically as more tolerant taxa.

Zone II was an impacted group of sites located downstream of the major point-source discharges in the Edmonton area. Total benthic invertebrate numbers were much higher than in Zone I and tolerant taxa were numerically dominant. Diversity index values dropped.

Zone III was a group of sites showing some recovery and situated downstream of Zone II. Total invertebrate numbers remained much higher than in Zone I, but the zoobenthic assemblages of Zone I and Zone III had features in common, as shown by similar diversity values and similar distributions of numbers among major taxonomic groups.

Municipal and industrial point-source discharges were responsible for the existence of zones of different water quality in the NSR from Devon to Pakan. The relative length of each zone at different times of the year was influenced by the flow rates and the water temperature regime.

Municipal discharges (wastewater treatment plant effluents, storm and combined sewer effluents) are the main contributors to the nutrient and total organic loads of the NSR. Certain invertebrate taxa responded to these point-source discharges by increasing in numbers. The magnitude and consistency of this type of response was greatest below the Gold Bar Wastewater Treatment Plant. The impact from storm and combined sewer effluents was most evident during summer and fall. During periods of heavy runoff, combined sewers known to discharge a mixture of sewage and surface runoff into the NSR induced a much sharper increase in invertebrate density than did storm sewers which discharged primarily surface runoff into the river.

Specific impacts of industrial discharges were masked by the enrichment effects of the Gold Bar Wastewater Treatment Plant. There were no consistent indications of an overall toxic effect in the study area delimited by the Devon and Pakan bridges. Enrichment, particularly below Fort Saskatchewan, had a greater impact on benthic invertebrates. However, the purpose of this study was to assess the integrated impact of all effluents on the water quality of a given section of the NSR, not to measure the impact of industrial point-source effluents.

Seasonal differences in water temperatures and flow rates explained the differences in the relative lengths of Zone II and Zone III in spring and fall. Biological and chemical breakdown processes take place more rapidly at higher temperatures, provided that dissolved oxygen levels are adequate. The NSR had satisfactory dissolved oxygen levels throughout the year in 1982, which permitted benthic invertebrates to recover faster below point-source effluents in the fall than in the spring. The faster recovery in the fall of

1982 was undoubtedly related to the scouring or cleansing process which accompanied the unusually high discharge in the spring of that year. Invertebrate data suggested the existence of a cyclic and dynamic pattern whereby the river bed is cleaned by scouring if spring peak discharges are adequate, and gradually enriched and fouled in downstream direction during summer and fall by discharges from the Edmonton urban area.

Synergistic Effects

The water quality and biota of the NSR downstream of the major sources of impact in the greater Edmonton area are unlikely to be affected in simple and entirely foreseeable ways as a result of significant and concurrent changes in several variables. Few, if any, factors are likely to act in isolation from other factors; the combined effect is the result of synergism and may or may not be readily predictable.

The absence or reduced intensity of the spring runoff peak in the NSR in any given year would result in a reduction in the scouring affect which normally occurs. High flow velocities and scouring usually remove attached plants from fixed substrates and wash loosely deposited sediments from the riverbed, affecting plant, invertebrate animal, and bacterial communities, as well as chemical variables. For instance, the development or recovery of certain plant communities in summer may be much faster and more extensive if spring runoff is greatly reduced in one or a succession of years.

Smaller river discharges in summer can result in greater water clarity, better light penetration, and warmer water temperatures. Similarly, smaller river discharge volumes in the NSR can cause higher concentrations of dissolved substances, such as nutrients, which come from various continuous municipal or industrial effluents in the Edmonton vicinity. One visible result of this combination of factors could be a marked increase in the growth of plants, such as epilithic algae and macrophytes.

The combined effects of reduced scouring, and increased water clarity and nutrient concentrations could be quite dramatic, even if nutrient loadings were near or below average. Consequently, it is possible to foresee a set of circumstances wherein a moderate reduction in nutrient loading would fail to produce the desired effects, at least in the short term. Conversely, an increase in nutrient loading could be masked during years of high spring and summer flow.

An extensive data base covering a period of years is basic to the assessment and prediction of impacts in a river like the NSR.

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